POST-TENSIONED SPLICED GIRDER BRIDGES IN CALIFORNIA

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ABSTRACT

California has been the "Post-Tensioned Concrete Bridge" State for many years. In past several years, applying matured post-tensioning system on precast girders, so called spliced precast girders, has been widely used on the purpose of reducing on-site construction time, minimizing traffic disruptions, and lessening environmental impacts. Also using post-tensioning precast bridge design and construction methods improves a great deal of seismic design and over-all bridge performance. Two years ago, Caltrans developed new Wide-Flange Girder with two typical sections, one specifically for post-tensioning system application. This paper reviews several typical post-tensioning precast bridge systems that are being used in California and illustrates several challenged post-tensioning precast bridge construction projects that successfully achieved project goals, as well as, shortening the construction time. The paper presents how Caltrans' post-tensioning precast bridge construction satisfies some constraints such as complex construction staging requirements, limited temporary overhead clearance, utility relocation, preservation of existing roadway alignment, permanent low overhead clearance, and maintaining existing traffic while meeting all design requirements. Furthermore, several lessons learned have been summarized and construction challenges and experience will be shared.

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

INTRODUCTION

In the past ten years, California Department of Transportation faced the many challenges to upgrade the State highway bridge system. Several of them are to build the new bridges projects with many restricted conditions and to widen the existing bridge projects. Usually, these kinds of highway bridge construction projects have the constraints such as longer span length, limited overhead clearance, complex construction staging requirements, utility relocation, preservation of existing roadway alignment, permanent low overhead clearance, and maintaining existing traffic, etc. While there are few conventional construction options are available to deal with such existing conditions, Caltrans has developed several unique bridge type and construction alternatives that combines both pre-tensioning and post-tensioning technology. The new type of precast/pre-tensioned concrete girder, named post-tensioned spliced girders, has been type selected and used often in California, especially in the last 3-4 years. A spliced girder is a long precast prestressed concrete girder that is fabricated in segments. These segments are assembled into a single girder or a continuous girder at the project site. Post-tensioning is generally used to connect the girder segments longitudinally. The bridge cross section is a structure in which a cast-in-place concrete composite deck is supported by multiple precast girders with the post-tensioning systems. The longitudinal post-tensioning in the spliced girders can be designed to create continuity in the superstructure. Additionally, if designed properly, the post-tensioning can be used to create an integral superstructure-to-substructure connection to meet seismic performance requirements. In California, the integral bent cap-to-column connection and integral superstructure to bent cap system are very important to meet seismic design requirements. With longer span capacity, 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.

Since Caltrans has lots of design and construction experience with post-tensioning girder bridges, combined with special seismic design requirements in California, design of spliced girders, which combines pre-tensioning precast/prestressed concrete girders with post-tensioning techniques, should be considered for the following reasons in California:

- Rapid construction with the use of precast elements reduces congestion, traffic delays, and total project cost.
- Longer span lengths reduce the number of piers and minimize environmental impact.
- Fewer joints in the superstructure improve structural performance, including seismic performance, reduce long-term maintenance costs, and increase bridge service life.
- The use of post-tensioning for continuity minimizes bridge superstructure depth, improving vertical clearance for traffic or railway.
- The smaller amount of required falsework minimizes construction impact and improves safety for the traveling public and construction workers.

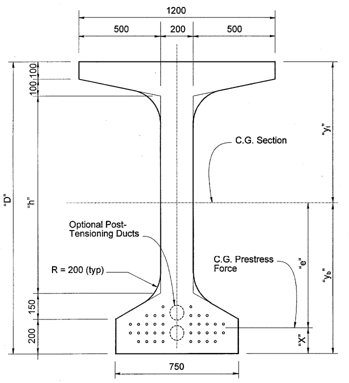
- Increased girder spacing reduces the number of girder lines and total project cost.

GIRDER TYPES FOR SPLICED GIRDER BRIDGES

When considering using post-tensioned spliced girder bridges, the first thing is to select types of precast girders. When the California “Bulb-Tee” and “Bath-Tub” girders were developed and first introduced in the late 1990’s, girder shapes, which could be spliced, were considered and girder webs were designed with 8” wide to accommodate the post-tensioning ducts. Therefore, when post-tensioning is used to splice either California “Bulb-Tee” or “Bath-Tub” girder segments together, span lengths of over 200 feet have been targeted. The depth-to-span ratio for post-tensioned spliced girders is approximately 0.040. In 2009, a new shape of girder which be called California Wide-Flange Girder was jointly developed by Caltrans, precast industry, and national experts. Two similar Wide-Flange girders with different web widths were introduced, one for pre-tensioned and another for post-tensioned. These two girders could use same precast form with variable web width (6.5” and 8”) along with same shapes for top flange and bottom bulb. The pretensioned Flange Girder girder is targeted for maximum span length of 150-160 feet due to the transportation restriction. The post-tensioned Flange Girder girder could span over 200 feet with splicing. The new WF girders have very efficient girder sections and could normally be spaced at the distance of two-times the bridge depth. Therefore, numbers of girder lines could be reduced. The depth-to-span ratio for post-tensioned spliced WF girders is approximately 0.038 to 0.040.

To avoid any congestion of pretensioning strands and post-tensioning tendons in the spliced girders, using straight strands is a much more desirable alternative than harping, by allowing maximum up to 33 percent debonded strands, to control tensile stresses at the top fiber of the girder ends. The cross-section, due to significantly wider top and bottom flanges, has a larger lateral moment of inertia. The increased stiffness in the weak direction requires minimal, if any, lateral bracing to prevent buckling failure during transportation.

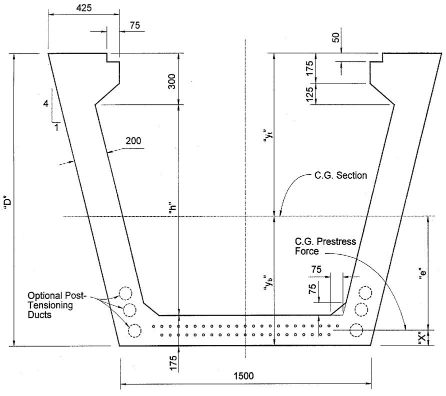
The followings are typical sections for using spliced girder bridges in California:



SECTION PROPERTIES

"D" (mm)	"h" (mm)	Area (mm^2)	I (mm^4)	y_b (mm)	y_t (mm)	S_b (mm^3)	S_t (mm^3)	r (mm)	Mass (N/m)	Wt. (Kg/m)
1400	850	596 500	155 400 E6	721	679	215.5 E6	228.8 E6	510	14 060	1433
1550	1000	626 500	201 200 E6	795	755	253.0 E6	266.5 E6	567	14 770	1505
1700	1150	656 700	254 200 E6	870	830	292.1 E6	306.2 E6	622	15 480	1577
1850	1300	686 100	314 500 E6	945	905	333.0 E6	347.5 E6	677	16 180	1650
2000	1450	716 300	382 600 E6	1019	981	375.4 E6	390.0 E6	731	16 890	1722
2150	1600	746 500	458 800 E6	1094	1056	419.4 E6	434.5 E6	784	17 600	1794

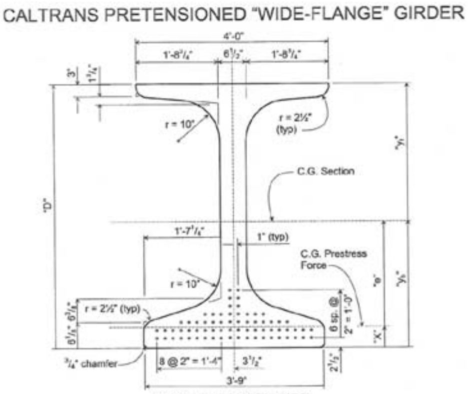
Fig. 1 CA “Bulb-Tee” Girder



SECTION PROPERTIES

"D" (mm)	"h" (mm)	Area (mm^2)	I (mm^4)	y_b (mm)	y_t (mm)	S_b (mm^3)	S_t (mm^3)	r (mm)	Mass (N/m)	Wt. (Kg/m)
1400	925	864 000	191 500 E6	612	788	313.0 E6	243.1 E6	471	20 370	2076
1550	1075	925 900	251 500 E6	683	867	368.2 E6	290.0 E6	521	21 820	2225
1700	1225	987 700	321 800 E6	755	945	426.2 E6	340.5 E6	571	23 280	2374
1850	1375	1 049 600	403 200 E6	827	1023	487.5 E6	394.1 E6	620	24 740	2522
2000	1525	1 111 400	496 400 E6	899	1101	552.2 E6	450.9 E6	668	26 200	2671
2150	1675	1 173 300	602 100 E6	972	1178	619.4 E6	511.1 E6	716	27 660	2819

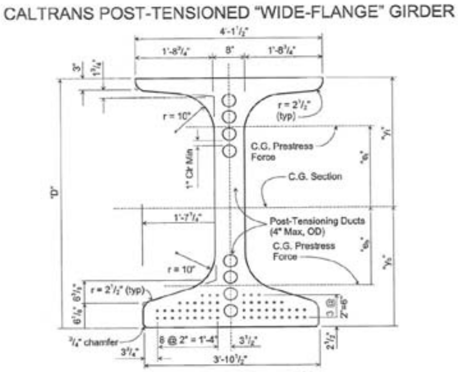
Fig. 2 CA “Bath-Tub” Girder



SECTION PROPERTIES

Size (ft-in)	"D" (in)	A (in^2)	I (in^4)	"y_b" (in)	"y_t" (in)	S_b (in^3)	S_t (in^3)	r (in)	w (lb/ft)
4'-0"	48	882	274 880	20.69	27.31	13 290	10 070	17.65	920
4'-6"	54	921	369 100	23.23	30.77	15 890	12 000	20.02	960
5'-0"	60	960	479 620	25.82	34.18	18 580	14 030	22.35	1 000
5'-6"	66	999	607 130	28.44	37.56	21 350	16 160	24.65	1 040
6'-0"	72	1 038	752 430	31.08	40.92	24 210	18 390	26.92	1 080
6'-6"	78	1 075	913 490	33.77	44.23	27 050	20 650	29.15	1 120
7'-0"	84	1 116	1 099 400	36.45	47.55	30 160	23 120	31.39	1 160
7'-6"	90	1 153	1 297 900	39.19	50.81	33 120	25 550	33.55	1 200
8'-0"	96	1 194	1 526 600	41.91	54.09	36 430	28 220	35.76	1 240
8'-6"	102	1 231	1 764 700	44.68	57.32	39 500	30 790	37.86	1 280
9'-0"	108	1 272	2 039 200	47.42	60.58	43 000	33 660	40.04	1 330
9'-6"	114	1 309	2 319 500	50.23	63.77	46 180	36 370	42.09	1 360
10'-0"	120	1 350	2 643 200	52.99	67.01	49 880	39 450	44.25	1 410

Fig. 3 CA Pretensioned "Wide-Flange" Girder



SECTION PROPERTIES

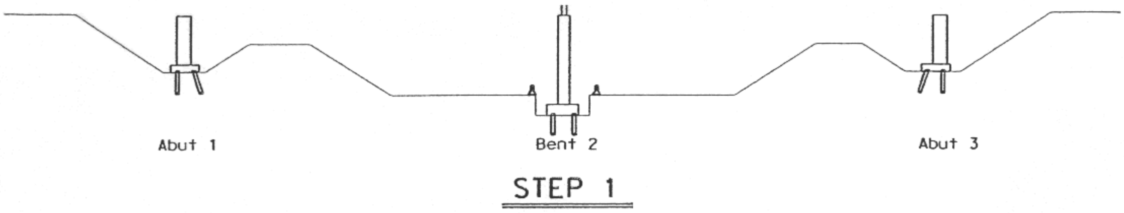
Size (ft-in)	"D" (in)	A (in^2)	I (in^4)	"y_b" (in)	"y_t" (in)	S_b (in^3)	S_t (in^3)	r (in)	w (lb/ft)
4'-0"	48	954	289 440	20.94	27.06	13 820	10 700	17.42	990
4'-6"	54	1 002	389 840	23.54	30.46	16 560	12 800	19.72	1 040
5'-0"	60	1 050	508 060	26.18	33.82	19 410	15 020	22.00	1 090
5'-6"	66	1 098	644 950	28.85	37.15	22 360	17 360	24.24	1 140
6'-0"	72	1 146	801 460	31.55	40.45	25 400	19 810	26.45	1 190
6'-6"	78	1 192	975 690	34.29	43.71	28 450	22 320	28.61	1 240
7'-0"	84	1 242	1 177 000	37.01	46.99	31 800	25 050	30.78	1 290
7'-6"	90	1 288	1 393 100	39.80	50.20	35 000	27 750	32.89	1 340
8'-0"	96	1 338	1 642 000	42.56	53.44	38 580	30 730	35.03	1 390
8'-6"	102	1 384	1 902 800	45.38	56.62	41 930	33 610	37.08	1 440
9'-0"	108	1 434	2 202 900	48.16	59.84	45 740	36 810	39.19	1 490
9'-6"	114	1 480	2 511 700	51.01	62.99	49 240	39 870	41.20	1 540
10'-0"	120	1 530	2 867 100	53.81	66.19	53 280	43 320	43.29	1 590

Fig. 4 CA Post-Tensioned "Wide-Flange" Girder

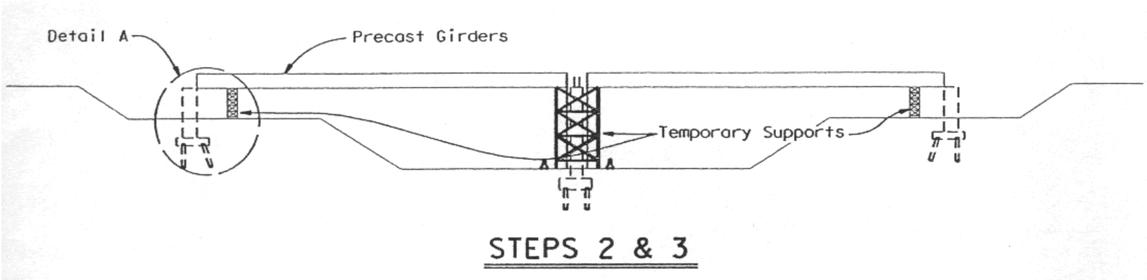
STRUCTURAL TYPES FOR SPLICED GIRDER BRIDGES

Spliced precast girder structure types and construction sequence could vary based on bridge span length, numbers of bridge spans and locations of falsework. The following figures show several spliced precast girder construction sequence with different post-tensioning splicing techniques.

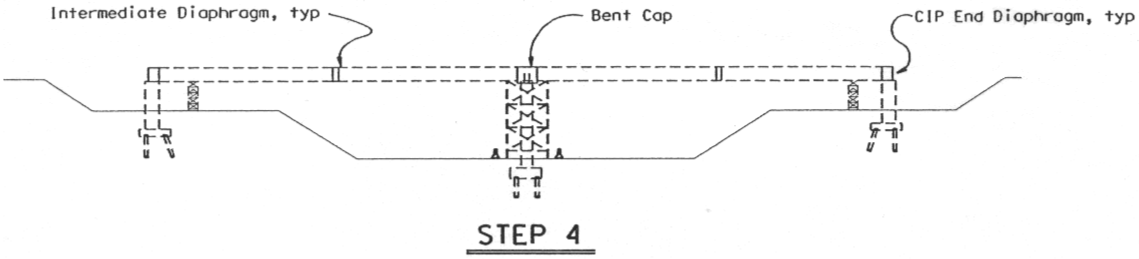
Two Span Spliced Girder Construction Sequence



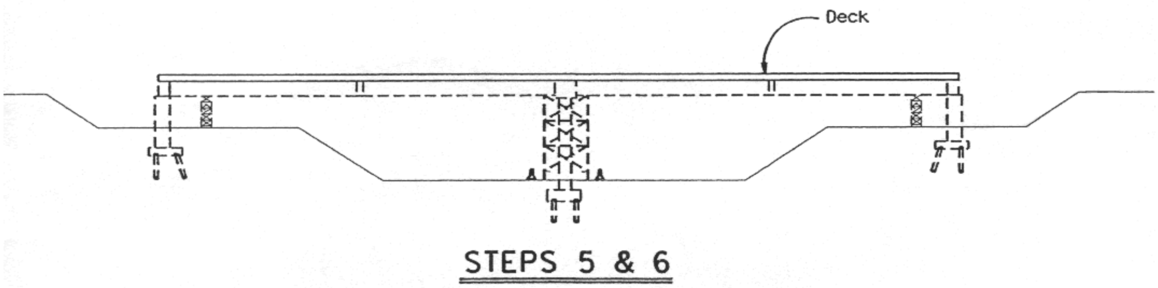
Girder is cast at precasting plant while the substructures are constructed.



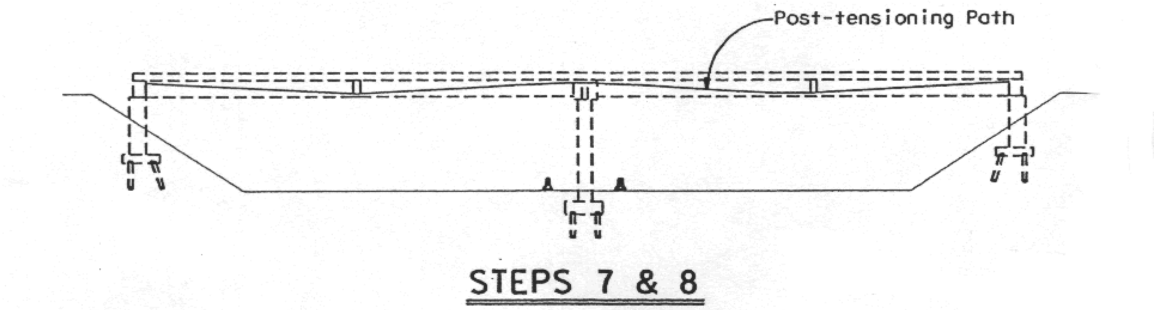
Erect temporary supports, and set girder in place.



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



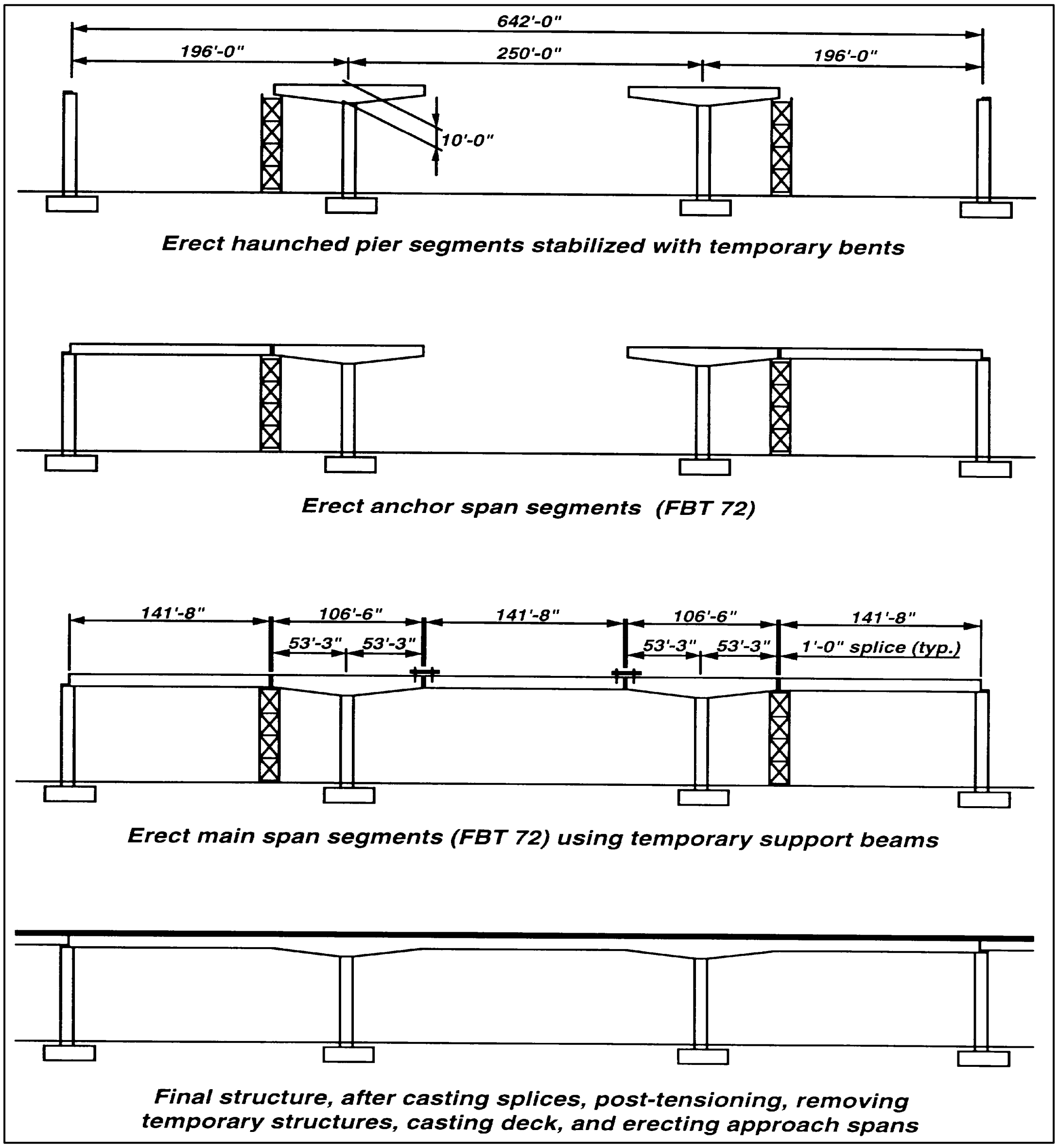
Allow CIP portions to reach min concrete strength, then place deck concrete. The temporary supports remain in place as a redundant support system.



Post-tension superstructure, remove temp supports, and complete construction of abutments.

Fig. 5 Typical Two Span Spliced Girder Construction Sequence

Three Span Spliced Girder Construction Sequence



Erect haunched pier segments stabilized with temporary bents

Erect anchor span segments (FBT 72)

Erect main span segments (FBT 72) using temporary support beams

Final structure, after casting splices, post-tensioning, removing temporary structures, casting deck, and erecting approach spans

Fig. 6 Typical Three Span Spliced Girder Construction Sequence

Multi-Span Spliced Girder Construction Sequence

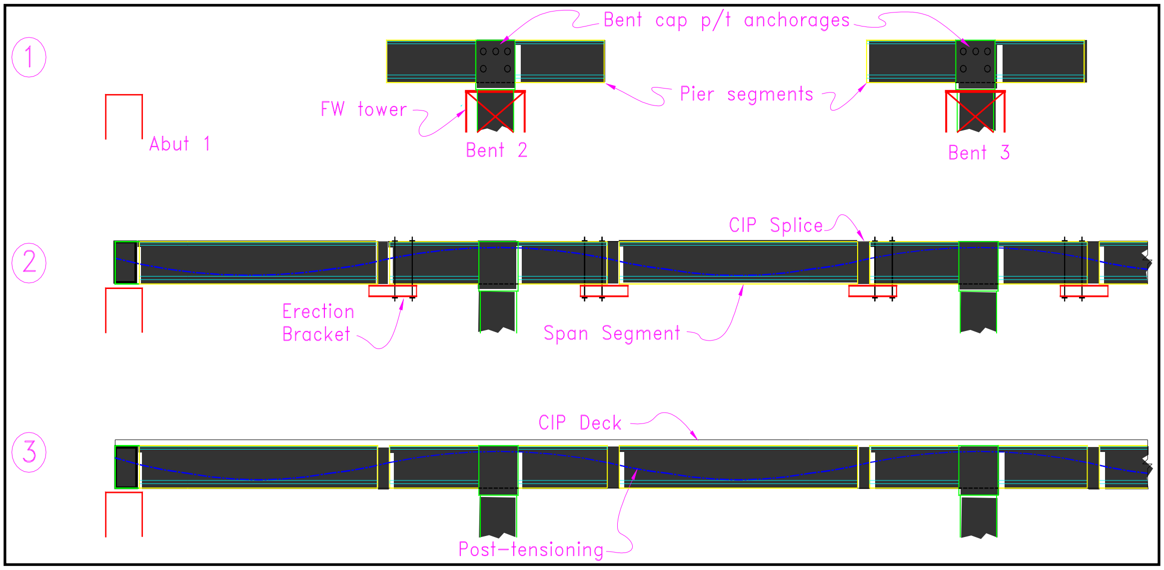
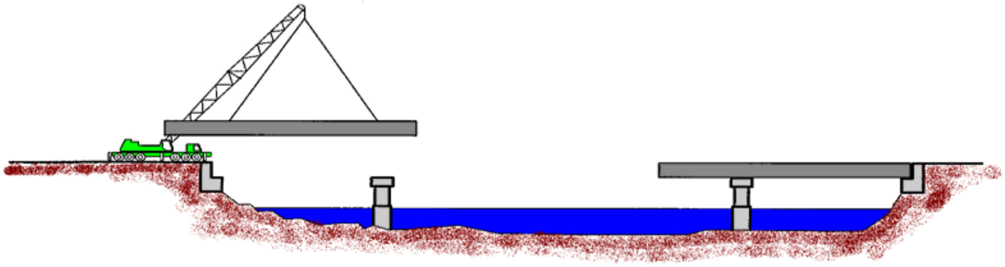


Fig. 7 Typical Multi-Span Spliced Girder Construction Sequence

Spliced Girder Construction Sequence Over Water



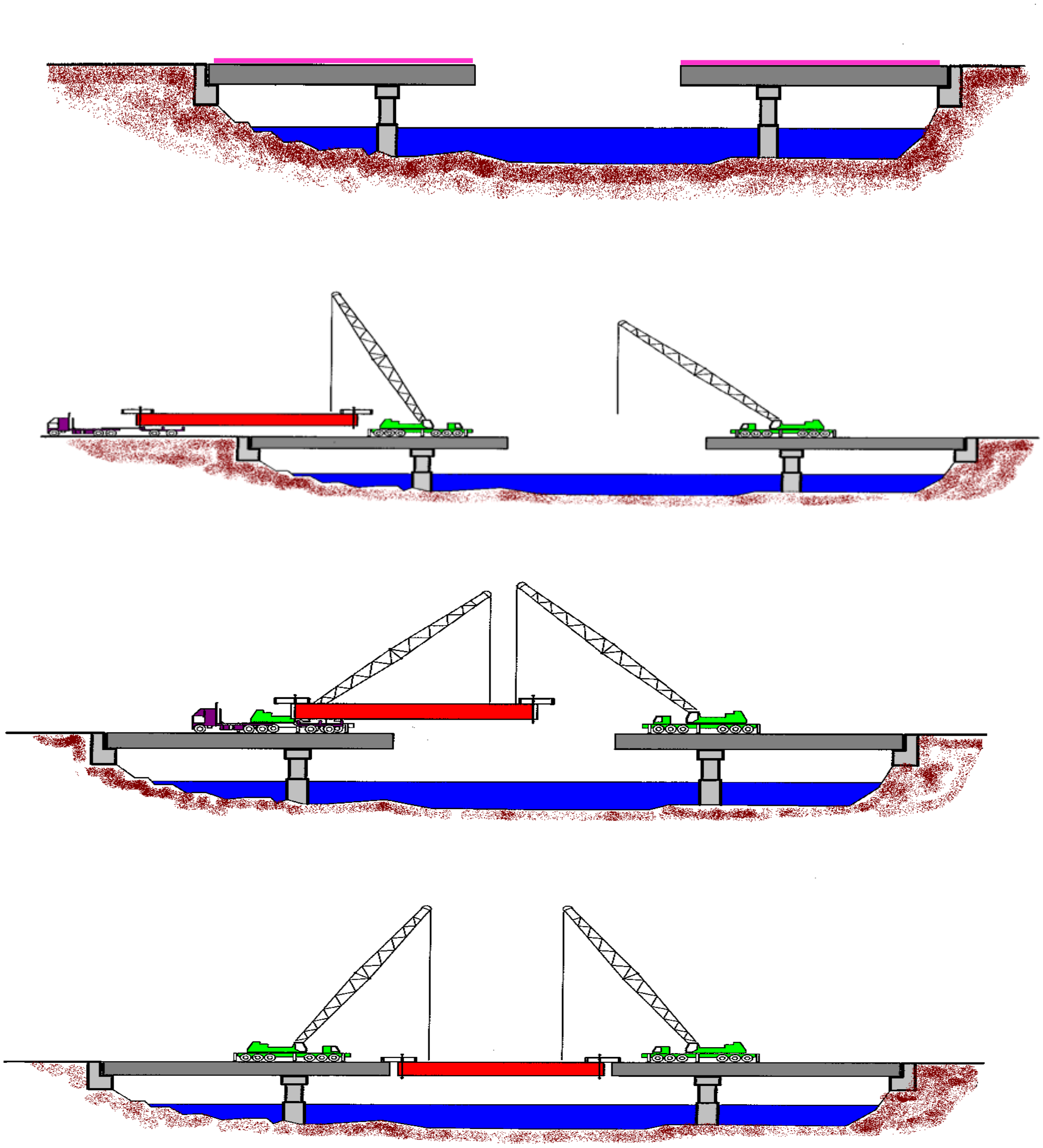


Fig. 8 Spliced Girder Construction Sequence Over Water

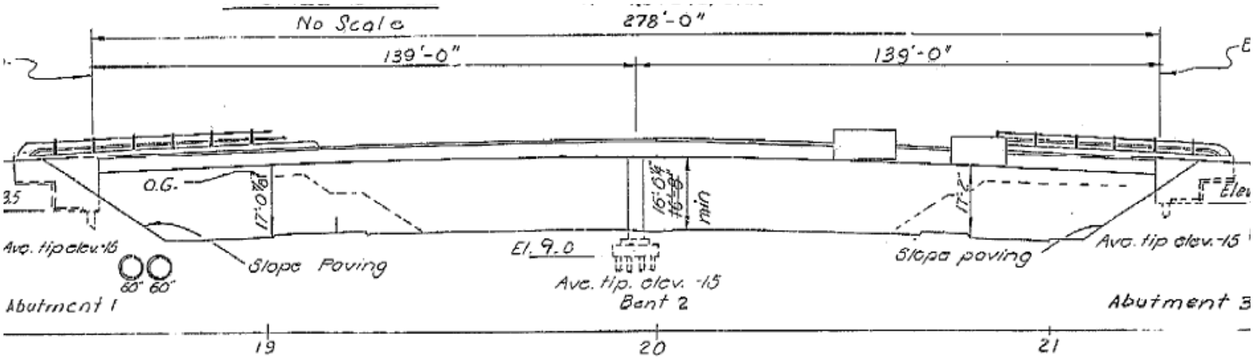
Caltrans has applied all above-mentioned post-tensioning construction sequences to various spliced precast girder projects. The following lists several typical and unique spliced precast girder bridge projects constructed in California in past ten years. Caltrans, along several California Consultants, have designed all these bridge projects and some of them will be presented during the conference.

- Sacramento River Bridge – First integral superstructure-to-substructure (with post-tensioned dropped bent cap) spliced Bulb-Tee girder bridge in California
- Via De La Amistad UC – First simply supported spliced Bath-Tub girder bridge in California
- Fibreboard UC – First spliced replaceable deck Bulb-Tee girder bridge in California
- Highway 99/120 Separation Bridge – First integral superstructure-to-bent spliced Box Girder bridge in California
- Angeles Crest Bridge – First span length over 200 feet spliced simply supported Bulb-Tee girder bridge in California. Won 2009 PCI Design Award Span Length Over 150 feet.
- Harbor Blvd OC – First continuous integral superstructure-to-substructure spliced Bath-Tub girder bridge in California
- Feather River Bridge – Longest (over 2000 feet) post-tensioned spliced modified Bulb-Tee girder bridge in California
- Petaluma River Bridge – Maximum span length of 212 feet (total 907 feet) post-tension spliced haunched Bulb-Tee girder bridge in California
- Reigo Road OC – First continuous integral superstructure-to-substructure spliced Wide-Flange girder bridge in California

CASE STUDIES FOR CALIFORNIA POST-TENSIONED SPLICED GIRDER BRIDGES

The following case studies show Caltrans applies post-tensioned spliced precast girder design not only for regular highway bridge design and construction but also for large-scale bridge design and construction projects in past five years.

- **Harbor Blvd Overcrossing (Widen)**:
  - Listed below is a summary of Harbor Blvd Bridge Widening Project:
    - Bridge Constraints: Vertical Clearance, Structure depth required to be less than 5’-7”, Match existing structure type, Avoid inverted-T bent cap, No Falsework
    - Superstructure: Two 139’ Spans, Post-tension Spliced Precast Bath-Tub Girders
    - Substructure: Integral bent cap with fixed at top and pinned at bottom columns. No moment into the footing means smaller footings, fewer piles.
    - Lessons Learned: 1. Elimination of Greased Metal sheet in Bearing Pad Detail 2. Camber Diagram Control 3. Construction Sequence and End Diaphragms 4. Bent Cap Reinforcement Congestion 5. Minimum Construction Areas



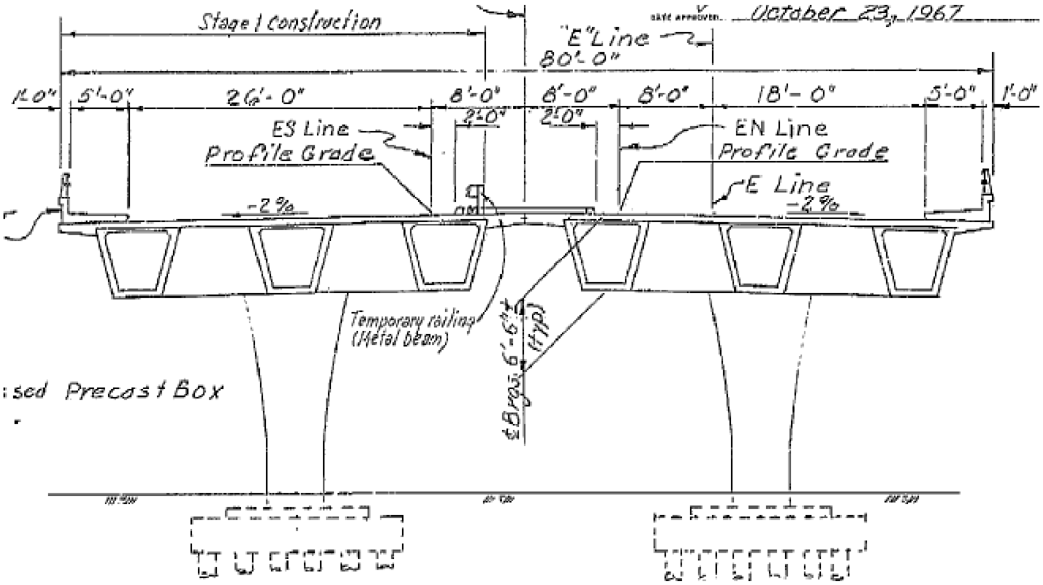
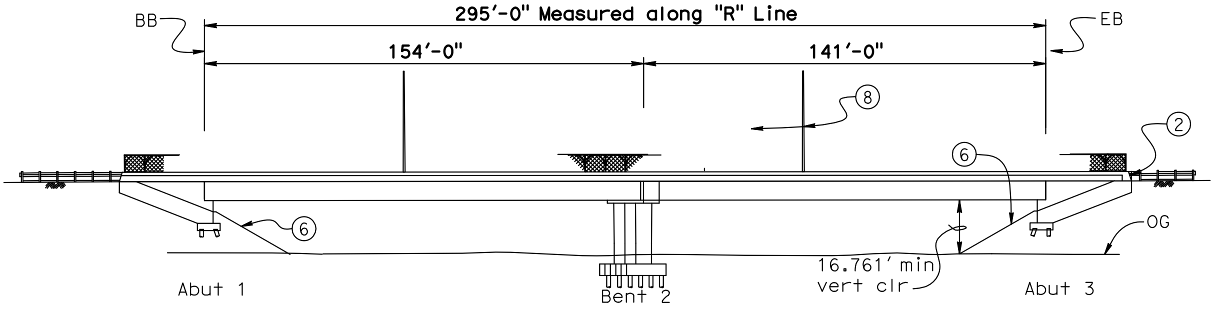
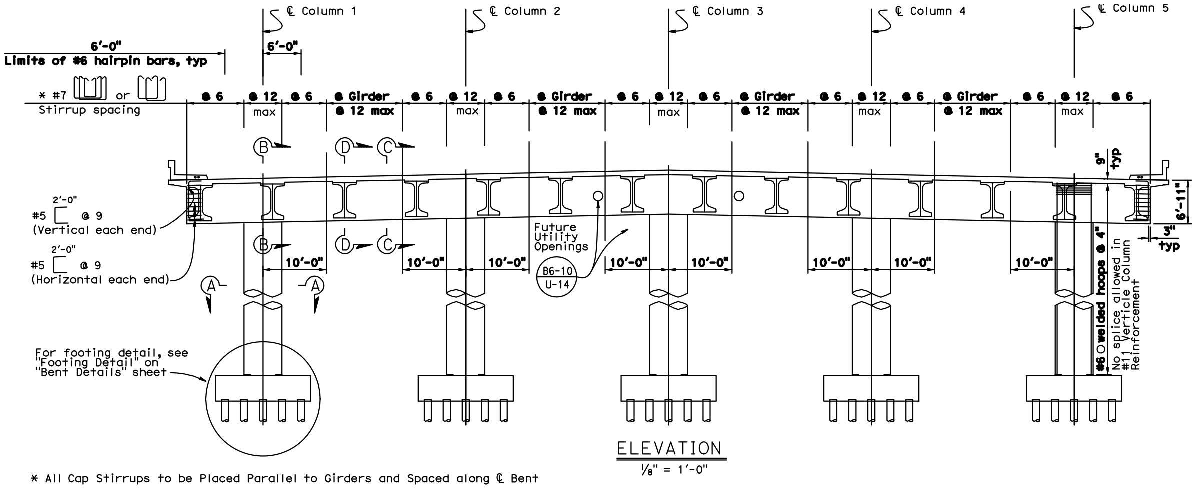


Fig. 9 Harbor Blvd Overcrossing Figures

- **Reigo Road Overcrossing**:
  - Listed below is a summary of Reigo Road Bridge Project:
    - Bridge Constraints: Vertical clearance, Lower bridge profile saves one million dollars for the project
    - Superstructure: 154’-141’ spans, 156’-4” wide, Post-tension Spliced Caltrans new Wide-Flange Precast Girders, WWF for Shear Reinforcement
    - Substructure: Integral bent cap with fixed at top and pinned at bottom columns. No moment into the footing means smaller footings, fewer piles.
    - Lessons Learned: 1. No superstructure falsework saves total project cost 2. Advantages of two stage post-tensioning 3. No sag girders 4. Concrete strength controlled by shear design 5. Camber Diagram Control





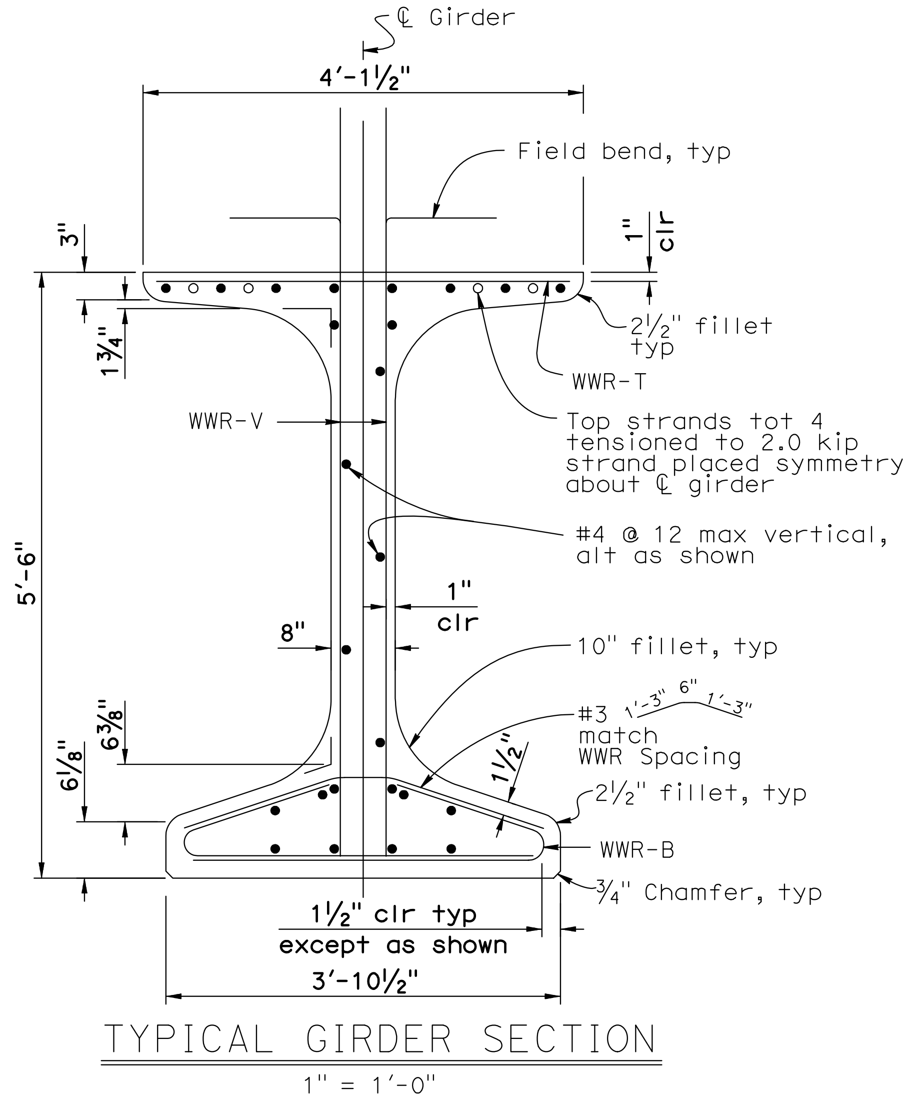
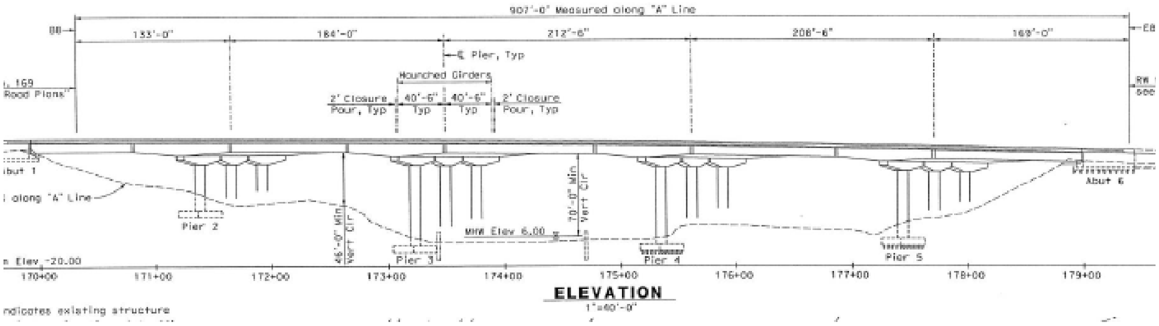


Fig. 10 Diego Road Overcrossing Figures

- **Petaluma River Bridge (Replacement)**:
  - Listed below is a summary of Petaluma River Bridge Project:
    - Bridge Constraints: Environmental Sensitive Area, Long Spans, No Falsework
    - Superstructure: 907 feet long bridge, 133'-180'-212.5'-212.5'-169' Spans, Two Stages Post-tension Spliced Haunched Bulb-Tee Girders with Strong Backs
    - Substructure: Prestressed bent cap, Multi-columns bents, PTFE/Spherical Bearings

- Lessons Learned: 1. Superstructure Construction Sequence with Time Dependent Assumptions 2. Prestressed Bent Cap 3. Camber Diagram Control 4. PTFE/Spherical Bearings



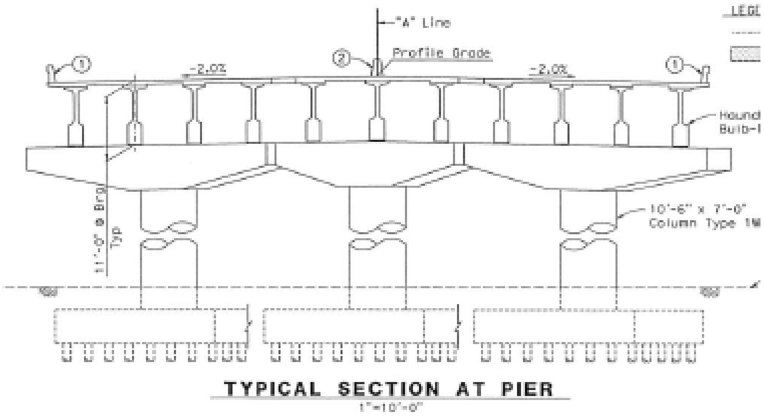


Fig. 11 Petaluma River Bridge Figures

LESSON LEARNED

During the design and construction of more than twenty post-tensioned spliced girder bridges, several lessons have been learned in California and some of design and construction experience are listed as follows:

- Spliced girder bridge design normally consists of precast pretensioned girders and post-tensioning. Therefore, the prestress notes for both pretensioning and post-tensioning shall be shown on the bridge plans.
- Precast girders can be either spliced on bridge site on temporary towers or spliced on the ground near the project site and then erected.
- The designer must take into account the construction sequence and staging. Temporary supports and locations shall be considered and designed properly as these affect the girder section, span length, and pretensioning and post-tensioning force. Temporary support locations and reactions for each stage of construction shall be shown on the contract plans or standard special provisions.
- The service limit state must be addressed in design considering both temporary and final concrete stresses in girder segments at each stage of pretensioning and

post-tensioning as well as all applicable loads during construction. The strength limit state only needs to be considered for the final construction stage.

- Post-tensioning may be applied to precast girders before and/or after placement of the deck concrete. When post-tensioning is applied to the girders both prior to and after placement of the concrete deck, it is referred to as two-stage post-tensioning. In general, one-stage post-tensioning is relatively simple in design and construction and is mostly used with bridge span lengths less than approximately 120 feet. Normally, it is desirable to apply all of the post-tensioning after the deck becomes part of the composite deck-girder section. When the full post-tensioning force is applied prior to deck placement, this allows for future deck replacement or can meet other project specific requirements. In this one-stage approach, the post-tensioning force and girder compressive strength (*f'c*) are usually higher than that required for post-tensioning to the composite section or for two-stage post-tensioning. When the bridge span length exceeds approximately 120 feet and/or the precast girders are in segments, two-stage post-tensioning typically results in a more efficient bridge system. The first-stage post-tensioning is designed to control concrete stresses throughout the continuous span for the loads applied before the second stage of post-tensioning. The second stage post-tensioning force is usually designed for superimposed dead loads and live loads. Benefits of the two-stage post-tensioning method include: lower required pretensioning force, more efficient total post-tensioning force for the structure, lower required *f'ci* and *f'c* for the precast girder, and better deflection control.
- Prestress losses due to the effects of pre-tensioning, post-tensioning, and possible staged post-tensioning shall be considered. Time dependent software may be used to properly account for prestress losses associated with multiple stages.
- Instantaneous deflections due to post-tensioning at different stages should be shown either on the design plans or Resident Engineer pending files. These deflection values will be used to set screed grades in the field.
- The post-tensioning tendon profile shall be shown on the design plans. Although a specific tendon placement pattern may not be provided in the bridge plans, the designer shall develop at least one workable tendon placement solution at all locations along the span, including at anchorages. Tendon duct size shall be based on a duct area at least 2.5 times the total area of prestressing strands. The outside duct diameter shall be less than one half the girder web width and shall be shown on the design plans. The maximum number of strands per tendon shall not exceed 19-0.6" diameter strands. In design, a duct size should be assumed and taken into consideration for web shear capacity reduction.
- Wet closure joints between girder segments are usually used instead of match-cast joints. The width of a closure joint shall not be less than 24 inches and shall allow for the splicing of post tensioning ducts and rebar. Web reinforcement, A_v/s, within the joint should be the larger of that provided in the adjacent girders. The face of the precast segments at closure joints must be intentionally roughened or cast with shear keys in place.

SUMMARY

In the past ten years, Caltrans has taken all the advantages and benefits of post-tensioned spliced precast girder bridge systems and utilized several innovated construction methods to meet the California specific challenges such as longer continuous span lengths bridges, seismic resistant bridge connections, and total project cost reduction. Due to the mature practice of low cost post-tensioning construction techniques in California, Caltrans has combined technologies of precast/prestressed concrete elements and post-tensioning systems together, and has designed and constructed many different types of spliced girder bridges. Nowadays, spliced girder bridge becomes one popular bridge type alternative and it really shows the benefits of its applications. Although only 20-25% of California precast bridges are designed and constructed using post-tensioned spliced girders right now, it can be foreseen that more and more spliced girder bridges will be built in the coming decades.

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