RECOMMENDATIONS FOR IMPROVED DETAILS AND GUIDELINES FOR PARTIAL-DEPTH PRECAST DECK PANELS TO ACCELERATE BRIDGE CONSTRUCTION IN CALIFORNIA

Eric E. Matsumoto, PhD, PE, Department of Civil Engineering,
California State University, Sacramento, CA

ABSTRACT

Despite the relatively slow pace in implementation of Accelerated Bridge Construction (ABC) practices within California, significant changes are underway to implement Prefabricated Bridge Elements and Systems (PBES). Although most attention has been paid to research and development of seismic substructure systems using reliable connections, California is still in its formative stages in adopting some PBES such as Partial-Depth (stay-in-place) Precast Deck Panels (PDPs). This paper firstly traces the history of the use of PDPs in California over the past two decades, including challenges that led to disfavor of PDPs and subsequent research to address issues. Results of a recently-completed PDP survey of California precasters, engineers, and contractors are then reported, including project experience with PDPs, perceived advantages and issues, as well as problems, mitigation, and suggested improvements. Based on survey results, detailed recommendations are presented for improved details and guidelines for PDP use within the context of Caltrans bridge practice. Implementation of these recommendations are expected to significantly improve design, fabrication, and construction of PDPs and to provide California—and other states with limited use of PDPs—an important tool to accelerate bridge construction.

Keywords: Precast Deck Panel, Partial-Depth, Survey, Accelerated Bridge Construction, Details, Specifications

INTRODUCTION

In California, the increasing demands being placed on the transportation network with its aging infrastructure have inevitably led to the need for bridge structures to support rapid replacement, widening, and new highway infrastructure.[1] The California Department of Transportation (Caltrans) has recognized Accelerated Project Delivery as a critical approach to meet the state's mission, and Accelerated Bridge Construction (ABC) has become an integral part of the solution.

Recent updates in bridge 2015 Memo to Designer Section 1-8 (MTD 1-8), Planning Studies[2], and 2014 MTD Section 1-29 (MTD 1-29), Structure Type Selection[3] demonstrate Caltrans commitment to ABC. Regarding Advanced Planning Studies (APS), MTD 1-8 states: "The basic objective of an APS is to develop, as early as possible, a feasible type of structure, cost, project risk and controls appropriate for the specific site location." Regarding ABC, MTD 1-8 states:

> Accelerated Bridge Construction (ABC) methods shall be considered to reduce construction impact times, mitigate environmental constraints, or to manage a significant project risk. During the K-phase (Project Initiation phase), ABC should be taken in consideration along with conventional construction methods.

Another important guidance document in project development, MTD 1-29, states:

> The Structure Type Selection Meeting is intended as a critical mechanism of the Structure Type Selection process for involving essential units in the project development and constructability review process prior to General Plan distribution. The meeting's primary objective is to obtain consensus on and approval for, a structure type proposed for each structure presented before starting detailed design. The meeting's general objectives and desired outcomes are part of the project development process. Among these objectives and outcomes are to:…(10) Consider Accelerated Bridge Construction (ABC) implementation.

It is noteworthy that inclusion of ABC considerations as an integral part of Caltrans bridge practice, especially at the APS and Type Selection stages, signals a significant commitment to Accelerated Project Delivery as well as ABC as a viable alternative approach to conventional cast-in-place (CIP) construction practices. As noted in the Caltrans ABC Lessons Learned Report[1]:

> In California, cast-in-place (CIP) construction has been the mainstay ("bread-and butter") practice for the majority of bridges. This structure type yields construction cost effectiveness and predictable seismic performance. Typical CIP operation needs extensive preparatory, casting and finishing time, and usually many concrete bridges require complex falsework systems, which adversely affects traffic movement during construction. In an effort to address accelerating bridge construction, the California Department of Transportation (Caltrans) has begun to investigate and deploy viable alternatives to conventional construction.

Regarding actual systems to implement ABC, the ABC Lessons Learned Report states[1]:

> To achieve accelerated bridge construction (ABC) that reduces on-site construction time and mitigates long traffic delays, Caltrans engineers are developing new practices to design alternative bridge types using precast, segmental, and steel structure types….Alternative approaches include precast or prefabricated structural elements…Prefabricated elements reduce overall on-site construction time, and also eliminate the need for falsework, thereby mitigating impacts to the traveling public. In addition, prefabricated components, when produced in a manufacturing facility or offsite, enhance quality control of the product. In California, prefabricated elements, such as precast concrete girders, abutments, steel girders, and others, currently lead the discussion of ways to accelerate on-site project completion.

Therefore, despite the relatively slow pace in implementation of ABC practices within California compared to other states, significant changes are underway, with focus on Prefabricated Bridge Elements and Systems (PBES).[4] Understandably, much attention in California has been paid to recent research and development of seismic substructure systems using reliable connections between precast bent caps, girders, columns, and footings.[5,6] However, California is still in formative stages in adopting some PBES such as partial-depth, stay-in-place precast deck panels (PDPs), the subject of this paper.

The FHWA Connection Details Manual for PBES defines partial-depth precast deck panels as: “A bridge deck system that consists of relatively thin precast concrete panels that span between supporting members that are made composite with a thin layer of sitecast reinforced concrete. The precast panel makes up the bottom portion of the structural slab. The site cast concrete makes up the remainder of the structural slab.”[7] PDPs serve as both a stay-in-place form for the CIP topping as well as a working platform for placement of deck reinforcement. In PDPs, the prestressing strands are placed in the span direction of the panel, transverse to the bridge and perpendicular to the longitudinal axis of the girders. Due to their location in the PDP, strands serve efficiently as primary positive moment reinforcement not only for the initial stages at transfer and under construction loads as a non-composite section, but also at the later stages of service and strength levels for superimposed dead and live loads as a composite full-depth bridge deck. Figure 1 shows placement of a representative precast deck panel followed by deck reinforcement on the 2014 Glen Helen Road Undercrossing (Widen) Project on I-15 near Devore in Southern California.

This paper firstly traces history of the use of PDPs in California over the past two decades, including challenges in design, fabrication, and construction that led to disfavor of PDPs, as well as subsequent research to address some of these issues. Then, an overall approach to reestablish the use of PDPs for ABC in California is presented. Related to this, results of the Fall 2014 PDP survey of California precasters, engineers, and contractors are summarized, including project experience, perceived advantages of PDPs, issues of concern/challenges, problems and mitigation, and suggested improvements. Based on survey results and industry discussions, recommendations are presented for improved details and guidelines for PDP use in California.

a) Placement of Deck Panel b) Deck Reinforcement before casting of CIP Topping

Figure 1. 2014 Glen Helen Road Undercrossing (Widen) on I-15 in Southern California

HISTORY OF PARTIAL-DEPTH PRECAST DECK PANEL USE IN CALIFORNIA

Caltrans released MTD 8-6, Use of Prestressed Concrete Deck Panel Stay-in-Place Forms, in 1983. Together with MTD 8-6, Caltrans developed Bridge Standard Detail (XS) Sheets to provide the contractor an optional method of deck construction using "precast-prestressed deck panels as a stay-in-place form that works compositely with the cast-in-place deck."[8] The only stated benefit was greater safety than conventional CIP construction for workers and the traveling public; interestingly, speed of construction was not mentioned. Criteria included requirement for parallel girders for steel (but not precast concrete) girders, placement of longitudinal deck bars directly on PDPs with 10% increase in development length, and use of fiberboard filler for supporting PDPs using a thickness not to exceed 3 in.

Although PDPs were permissible, few projects with precast concrete or steel girders used them. Steel stay-in-place metal forms (SIPMF), which were included in Caltrans Standard Specifications and shown as an alternative on Standard Sheets, were the preferred option, despite the requirement for decks using SIPMFs to be designed for an additional 10% dead load (due to the presence of corrugations) and the challenge for field inspection of decks.[9]

SAN MATEO-HAYWARD BRIDGE WIDENING PROJECT

One notable project using PDPs was the 2001 San Mateo-Hayward Bridge Widening (SMHB) Project.[10] A California record-setting 18,930 PDPs were used to eliminate slow, costly interior bay formwork and removal associated with CIP construction. Panels were approximately 5 ft 2 in (panel span direction) by 8 ft 4 in (bridge longitudinal direction) x 3-1/8 in thick and used 3/8 in diameter, grit-impregnated epoxy-coated strand with welded wire mesh (Figure 2). Strands were not extended out of the panel. Panels were also coated with polyuria to enhance durability. Due to the corrosive marine environment, the concrete mix design included a relatively high percentage of pozzolans, including 15 percent fly ash plus 7 percent silica fume. Special curing was used as a means to achieve the desired low

a) Placement of Deck Panel b) Cracking and Strand Slip at end of Panel

Figure 2. Partial-Depth Precast Deck Panels Use on San Mateo-Hayward Bridge Widening

permeability and avoid inherent cracking. Concrete strength was approximately 4000 psi at transfer and 5000 psi at 35 days.

As shown in Figure 2, cracks through the depth at the ends of panels were observed in the field before installation. Some cracks appeared immediately upon transfer. A report by Ben C. Gerwick, Inc. indicated that nearly 90% of the cracks occurred along the 3/8-in grit-impregnated, epoxy-coated strands. A rejection rate of approximately 30% led to extensive litigation.[11,12,13] Many factors were identified as potential causes of panel cracking, some believed to be synergetic:

- use of epoxy-coated strand with coarse grit, leading to transfer lengths shorter than that of black (bare) strand
- use of thin panels, providing less concrete to resist splitting stresses due to anchorage
- use of silica fume in mix, possibly contributing to early-age shrinkage
- raking the panel parallel to the strand up to 1/4 in, reducing the section
- improper handling at the precast yard
- inconsistent curing
- improper methods during casting, including hot weather methods and inconsistent mix
- handling in the field, including improper dunnage location to support panels and lifting panels at a point

Mitigation measures included: debonding strands at ends of panels, addition of strands combined with reduction in prestress force, addition of reinforcing steel adjacent to strands, and revised handling methods. During the project no clear solution was determined.[11]

In addition, after completion of the SMHB deck, cracks appeared in the CIP topping in distinctive patterns (Figure 3). Cracks in the CIP topping developed both longitudinally along

a) Cracks in Topping Slab

b) Close Up of Reflective Cracking

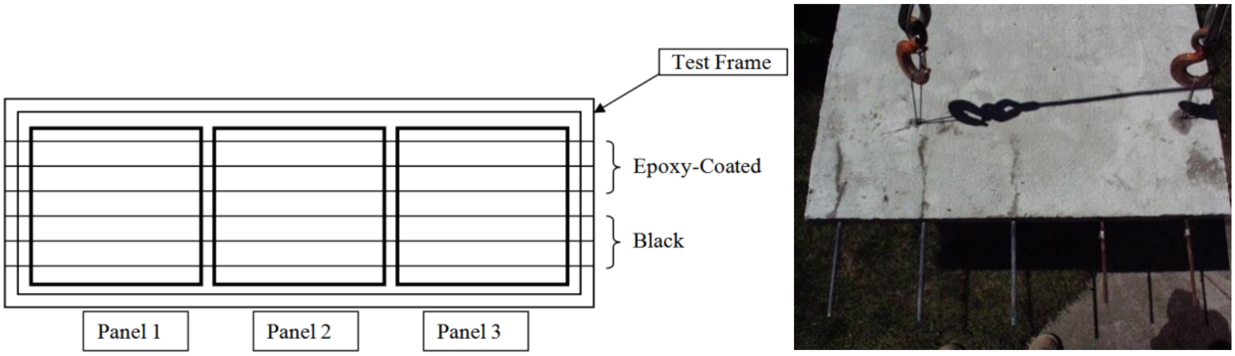
Figure 3. Reflective (Transverse) Crack Pattern in CIP Topping Slab Above Joint between Precast Deck Panels on SMHB [11]

the girder-to-panel lines as well as transversely between panels (reflective cracking). Cracks grew in width and length over time, and changes to the contractor's operations did not help. A change order was issued to apply Methacrylate to the entire surface of the bridge deck.[11]

TEST PROGRAM TO INVESTIGATE CAUSES OF PRECAST DECK PANEL CRACKING ON SAN MATEO-HAYWARD BRIDGE

Subsequent investigations led to some conclusions regarding the likely causes of PDP cracking.[12,13] During June-August 2001, the SMHB precaster, Pomeroy Corporation, conducted an internal test program to examine possible causes of cracking, specifically, the influence of 1) grit-impregnated, epoxy-coated strand and 2) silica fume added to fly ash on the SMHB PDPs. Because cracks were located at strands, the effect of strand type was examined (epoxy-coated vs. black). In addition, due to concerns over increased shrinkage cracking associated with the addition of silica fume to fly ash in the concrete mix, the effect of combined silica fume and fly ash on panel cracking was also a test parameter. The test program and results are summarized, based on and interview and unpublished documentation provided by the precaster.[12,13]

As shown in Figure 4, a total of 57 panels were cast, three at a time, in a 20 ft frame. The panel span length was the same as the SMHB production panel (5 ft 2in), but the panel width was 4 ft, approximately half the width of production panels. Six strands, 3 epoxy-coated and 3 black, were spaced at 8 in on center as in the production panels. Specimens were fabricated from one of two mixes: 1) mix of 7% silica fume plus 15% fly ash, matching the production panels or 2) a mix without any silica fume or fly ash. Panels were cast individually (Figure 4) and thus were not saw-cut but detensioned. Panel thickness was taken initially as 2.5 in (5 panels) and then increased to 2.75 in (10 panels). Although this final thickness was intended to simulate the 0.25 in reduction due to raking, it is also conservatively produced panels thinner than the 3-1/8 in production panels (less raking up to 0.25 in) to intentionally "induce cracking" in the deck to help identify causes of cracking.[13] The initial thin 2.5 in panels exhibited so many cracks that the effects of variables were difficult to discern, and thus panel depth was slightly increased. Panels were steam cured using a cycle similar to the production panels.



a) Test Setup b) Test Panel with Strand Extensions

Figure 4. Test Specimens to Investigate SMHB Deck Cracking [13]

Specimens were observed for cracking (number and location) both before and once a day after detensioning. In addition, strand slip relative to panel ends was monitored over time. Panels are categorized for four combinations: 1) black strand without supplementary cementitious materials (B); 2) epoxy-coated strand without supplementary cementitious materials (EC); 3) black strand with supplementary cementitious materials (B-S); and 4) epoxy-coated strand with supplementary cementitious materials (EC-S).

A crack was defined as "any visible separation within the concrete that ran the length of the strand." Cracking was observed at a significantly higher rate for panels with silica fume and fly ash (B-S, EC-S) compared to those without. B-S strands had 12 cracks and E-S had 47 cracks, compared to 2 cracks for B and 11 for E, i.e., 6 times and 4.3 times, respectively. In addition, cracking of panels before detensioning developed at a much higher rate for panels with silica fume and fly ash. For example, for a series of 12 panels, cracks appears at 44.4% of the strand locations in panels with silica fume, but 0% for strand locations in panels without silica fume. These results are consistent with research (e.g., Reference 14) on silica fume, which has demonstrated higher early-age shrinkage for silica fume concrete, especially when curing is limited, as in this research, to one day (vs. 7-day continuous moist curing recommended for bridge decks using silica fume). Cracks that appeared were initially very fine (hairline), originating at the ends of the panels, and grew in both width and length over time.

The effects of strand type and concrete mix are evident in the behavior of strand slip at ends of panels over time. Average strand slip vs. time (for a 12 panel series) is plotted in Figure 5. The significant effect of the grit-impregnated epoxy-coating is evident, when comparing slip for strands in panels with the same mix: E to B and E-S to B-S. At 3 days, the slip of E was only 32.4% of the B slip. No cracks developed, although this demonstrates that the grit used in the epoxy coating produced a greater bond (shorter transfer length) to the surrounding concrete than black strand. This larger bond, especially at ends of panels, corresponds to larger bursting/splitting stresses in the panel with grit-impregnated strand. The E-S slip was similarly found to be much smaller than the B-S slip, 48.8% at 3 days.

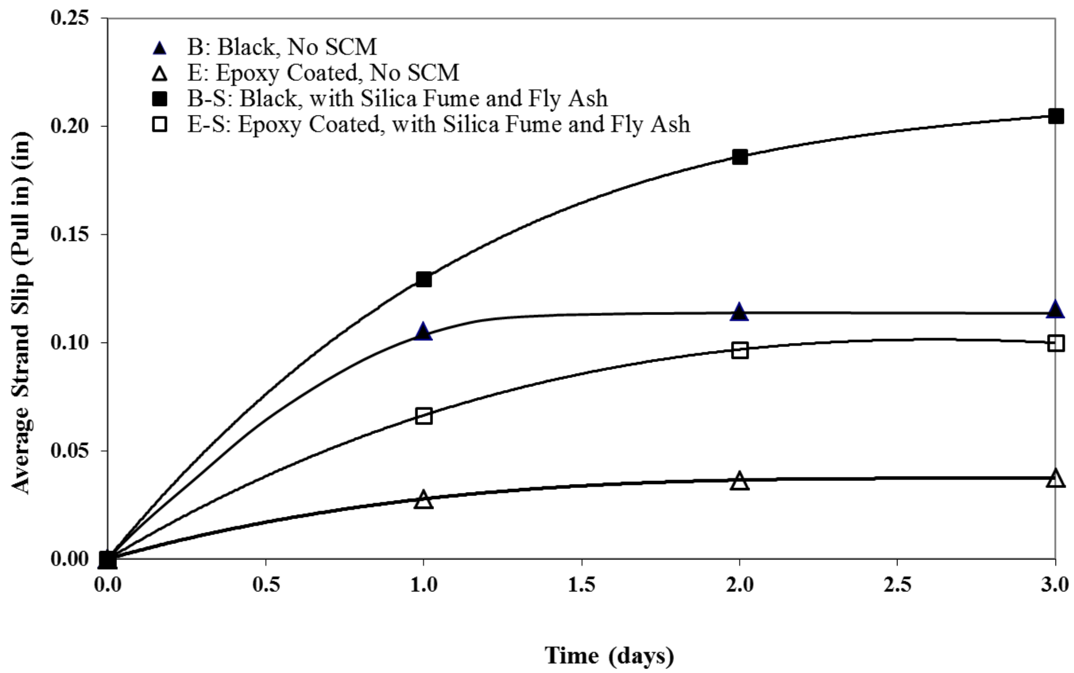


Figure 5. Average Strand Slip (Pull in) vs Time for Test Panels [13, Modified]

The E to E-S and B to B-S comparisons demonstrate the influence of silica fume in increasing strand slip: E slip was only 37.4% of E-S and B slip was only 56.3% of B-S. Although more cracks existed in the E-S and B-S panels prior to transfer than for the E and B panels, many additional cracks developed at or after transfer in the E-S panels compared to the B-S panels, at a ratio of 7:1.

A final comparison is that of E-S to B slip, which ranged from 63.1% to 86.6% over time. Although the silica fume mix increases cracking and slip, the epoxy-coating reduced slip more pronouncedly, though the slip at 3 days was very close. This case corresponds to the SMHB panels (E-S) and routine use of black strand (B). Although data shows slip compared closely, the use of the combination of epoxy-coated strand and silica fume in the mix led to a panel rejection rate of 30%. During the test program, panels were also rejected, if they had at least one crack at a strand after detensioning (not due to shrinkage before transfer). Twenty-two panels with epoxy strand were rejected and 10 panels with black strand were rejected. In addition, the number cracks at epoxy strands was 3.9 times that at black strands (55 vs 14). Furthermore, silica fume panels with epoxy strand had 15 rejected panels compared to 9 with black strands (1.7 times). Without silica fume, 7 panels with epoxy strands were rejected compared to just one with black strand.

Based on test results, the following conclusions were made:

1) Bond between the SMHB grit-impregnated epoxy-coated strand and concrete is much greater than that between black strand and concrete.
2) The use of the SMHB grit-impregnated epoxy-coated strand caused cracking at the strand locations at the ends of panels due to larger bursting/splitting stresses

3) Use of silica fume in the mix together with fly ash increased concrete shrinkage in the panels and caused cracking at strand locations, even before detensioning, and exacerbated cracking when combined with the use of SMHB grit-impregnated epoxy-coated strand.

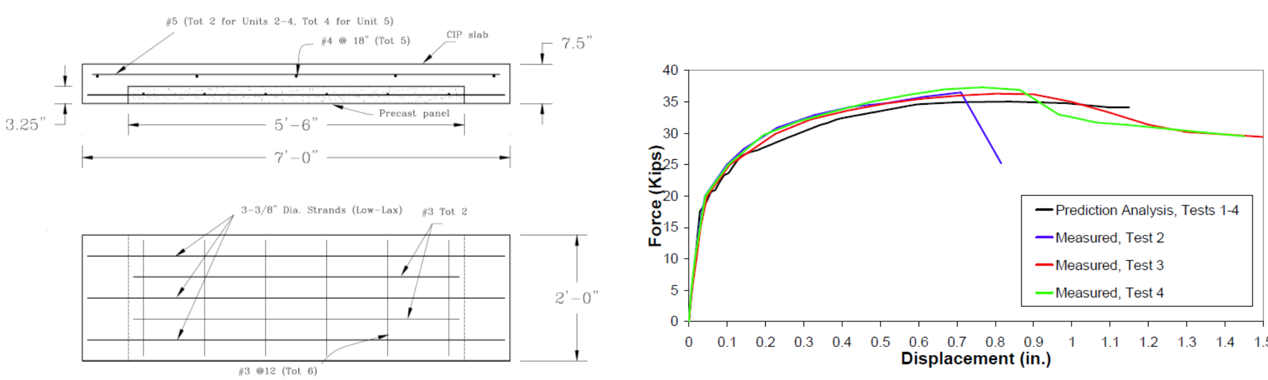
4) Thickness of panels is related to cracking, as thinner panels exhibited more cracking.

TEST PROGRAM TO VERIFY COMPOSITE BEHAVIOR BETWEEN PDP AND CIP TOPPING

PDPs were subsequently specified, especially for speed of construction, in 2006 for the SR-22 HOV Widen Design/Build Project in Orange County, the first design-build contract on an operating freeway in California. Interestingly, two areas of concern identified by the precaster for PDPs were eliminated from use: epoxy-coated strands and silica fume. In addition, deck panels were slightly thicker (3.25 in) and did not include raking that reduces the section around strands. However, associated with this project's use of PDPs, a series of five PDPs were tested at San Diego State University with support of the general contractor, precaster, and designer to verify composite action between the PDP and CIP topping. Medium broom (< 1/16 in), coarse broom (~1/16 in), and carpet drag finishes were investigated. As shown in Figure 6, tests demonstrated that full composite action was achieved without any horizontal shear slip at the interface regardless of the finish and with no reinforcement crossing the interface. Although some issues arose in the use of PDPs on SR-22 (e.g., reflective cracks and insufficient flow of concrete under deck panel edge for support), the SMHB issues identified by the precaster were eliminated.

CALTRANS CONCERNS OVER THE USE OF PDPS

The results of these two test programs and successful application of PDPs to the SR-22 project indicated that the problems with PDPs encountered on the SMHB can be prevented, and suggests that an appropriate learning curve in practice can be expected when PDPs are specified more regularly to allow the bridge industry to achieve greater familiarity and experience. Nevertheless, the problems that did arise cast a decades-long shadow over the



a) Test Specimens b) Load-Deflection Response

Figure 6. Verification Tests for Composite Behavior between PDP and CIP Topping [15]

use of PDPs in California, firstly by the removal of Caltrans PDP XS Sheets from use after the SMHB project, leaving SIPMFs as the recognized alternative to CIP decks for precast concrete or steel girder bridges, and then by the lack of development of design and construction specifications for PDPs.

Although SIPMFs have some of the advantages of PDPs, such as eliminating formwork during deck construction, increasing speed of construction and safety for workers and the travelling public, and reducing cost, they also have recognized disadvantages. [16,17] Key disadvantages include: 1) prevention of routine deck inspection from beneath the deck, 2) potential acceleration of deck deterioration by allowing larger amounts of moisture and deicing salts to concentrate within the deck, and 3) potential corrosion with associated risk to the traveling public and concerns over aesthetics. Caltrans prohibits the use of SIPMFs in Freeze Thaw Areas, which has led to the use of PDPs in recent projects located in these areas.

APPROACH TO REESTABLISH USE OF PDPS FOR ABC IN CALIFORNIA

Based on recent initiatives to promote and develop ABC practices as an integral part of an approach to achieve its mission, Caltrans has an active interest and commitment to develop PBES for ABC, and this important change has caused a renewed interest in PDPs. To reach its goal in using PBES, Caltrans is expected to develop a range of supporting bridge practice documents, through the Division of Engineering Services. For PDPs, it is anticipated that the following will gradually be developed as a comprehensive and complete “package” for proper implementation:

1) Updated Bridge Memo to Designers, MTD 8-6, Stay-in-place Precast Prestressed Concrete Deck Panels for Precast Concrete Girder Superstructures (in process), including design approach and other authoritative guidance for designers based on AASHTO LRFD and California Amendments
2) Bridge Standard Detail Sheets (XS Sheets), with Background Form and Notes (in process)
3) Standard Specifications, with detailed notes
4) Bridge Design Practice with design examples
5) Bridge Design Aids with design tables

All of these documents will ideally work together to help produce a safe, economical, and constructible design and thus increase the use of PDPs in California.

PDP SURVEY

SURVEY DESCRIPTION AND DISTRIBUTION

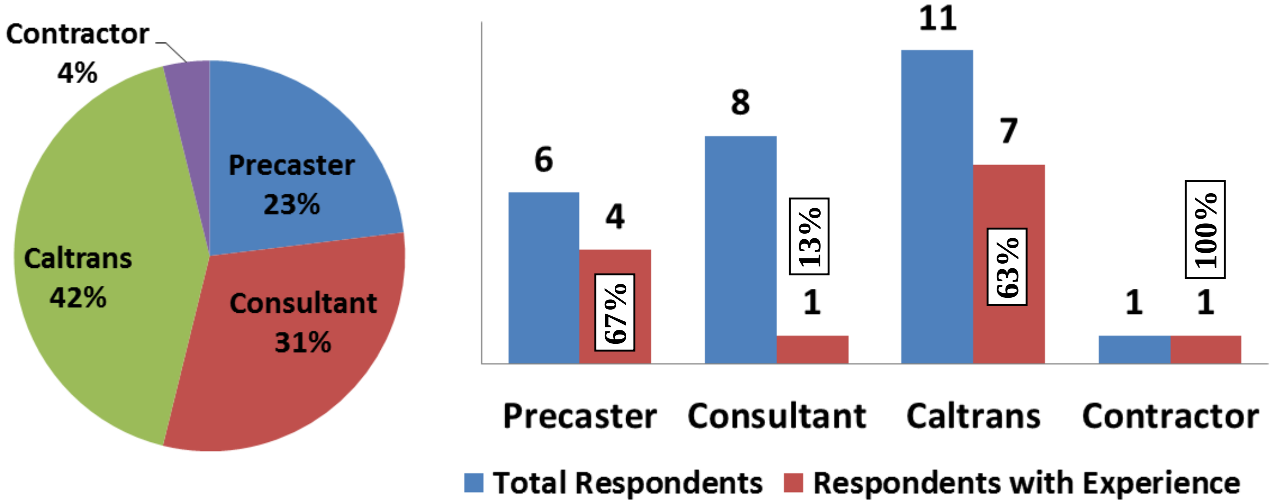
Based on the need for development of the above-mentioned Caltrans documents and discussions with Caltrans Precast/Prestressed Concrete Committee members and PCI West, a survey of California precasters, engineers (consultants and Caltrans), and contractors was conducted in Fall 2014 to acquire up-to-date information on the use and lack of use of PDPs on California bridges over the past 25 years.

The survey was divided into two parts: Part 1 for those without prior PDP experience, and Part 2 for those with prior experience. To gage the current situation in industry, the survey was developed to acquire both objective data and subjective opinions. The following issues were addressed for both parts, regardless of classification (precaster, engineer, contractor): 1) Reasons to use PDPs, with rankings; 2) Issues of concern or reasons not to use PDPs, with rankings; 3) Suggestions to improve use/implementation of PDPs; and 4) Available documentation. For those with prior experience, the following additional information was requested : 1) Summary of bridge information (reason for using PDPs, PDP system, Panel thickness, reinforcement, strand type, f'c, CIP topping, and Construction sequence); 2) Problems in design, fabrication, installation or service; and 3) Mitigation of problems. [18]

SURVEY RESULTS

Overall Distribution of Respondents

A total of 26 respondents completed the survey, including 6 precasters, 19 engineers (8 consultants and 11 Caltrans engineers), and 1 contractor. Figure 7 shows the distribution of respondents, as well as the percent with experience. Although precasters make up only 23% of the respondents, the number of precasters who responded represents, to the author's knowledge, the vast majority of precasters who fabricate precast bridges in the state, and all those who have past PDP experience. The number of Caltrans respondents represents a significant number of those with PDP experience in the state. Although the number of consultants and contractors with experience is limited, the survey collectively represents a significant voice of major stakeholders in the precast industry, especially in light of the number of actual California bridges represented by the survey (Table 1).



a) Distribution of Respondents b) Respondents with Experience

Figure 7. Number and Distribution of Respondents

Table 1. Summary of PDP Experience in California

California Bridge	Reason for Use	Precast Deck Panel Thick. (in)	Reinf. Type	f'c (psi)	Strand Extens. (in)	Support System	CIP Topping Thick. (in)	f'c	Bridge Age (years)	Problems Observed
San Mateo-Hayward Br (Widen)	FW (water)	3.19	EPR, WWR	5000	0	Conc/Rub	4.31	4000	14	TC,LC
SR-22 D/B (Widen), Multiple	Speed, FW	3.25	PR, WWR	4000	3-10	CAM	4.25	4000	9	SKEW, BR, TC
I-405 D/B, Multiple (Sunset Blvd OC, Skirball Ctr Dr OC, Ohio Ave UC, Sepulveda Blvd UC)	Engr Design	3.50	PR, WWR, MR	5000	6	CAM	4.25	4000	2	SPL, PC, CON, SKEW
North Torrey Pines Rd	FW (railroad)	4.00	PR,ECR	5000	3	CAM	5.00	4000	1	KEY, STR, DC, CON
I-15/I-215 D/B, Multiple [Glen Helen Pkwy UC, L/R (Widen); Glen Helen Rd (Widen); Cajon Creek L/R (Widen), Ramp; Devore L/R OH (Widen); Truck Bypass over Kenwood]	Speed, FW	5.00	PR, MR, WWR, EWWR	5000	4	CAM	4.63, 5	4000	Prog-1	SKEW, TC, LC, PC (non-rect), CON
San Gabriel River Bridge	Engr Design	3.50	PR, WWR	6000	6	CAM	-	-	Prog	
North Spring St Viaduct (Widen)	Engr Design	4.00	PR, WWR	5000	6	CAM	-	-	Prog	
Pine Lodge West OH	FW (railroad); Env. 3	3.50	MR	5000	N/A	CAM	4.75	5000	Prog	SKEW

LEGEND

Speed=Speed of construction, limited lane closures, FW=Eliminate/Reduce falsework during construction, PR= Prestressing strand, EPR=Epoxy-coated strand, ECR= Epoxy-coated reinforcement, WWR-Welded wire reinforcement, EWWR=Epoxy-coated WWR, MR=Uncoated mild reinforcement, CAM=Polystyrene Camber Strips, Conc/Rub=Rubber strip on concrete curb, Prog=In progress, TC=Transverse Cracking, LC= Longitudinal cracking, DC=Random high density deck cracking, PC=Panel cracking, SPL=Splitting cracks at end, SKEW=Cracking of skewed PDPs, BR=Flow of bearing concrete under PDP, STR=Camber strips broke/leaked, KEY=Panel cracking at thin keyway, CON=Constructibility issues (Strand-stirrup, bar extension conflict at diaphragm, Neg M reinf on Deck Panel, stirrup hook-PDP

Table 2. Summary of PDP Experience Outside of California [Adapted from Ref. 16]

State	PPC Panel Thickness (in)	Reinf. Type	f'c (psi)	CIP Topping Curing Method	f'c	Age (years)	Problems Observed
Kansas	3-3.5	PR, EC	4000	MC	4000	20	TC,LC
Florida	NR	PR, NC	NR	NR	NR	40	LC
Minnesota	3.5	PR,EC,WWR	6000	MC	4000	8	TC,LC
Texas	4	PR	5000	MC,WC	4000	25	TC,LC
Oklahoma	4	PR	5000	MC	4000	15	TC
Tennessee	3.5-4	PR	4000	MC,LM	4000	33	TC
Arkansas	NR	EC	5800	MC	5800	0	None
Hawaii	3.5	PR,MR	6000	MC,LM	4000	14	None
Michigan	NR	EC	4000	MC	4000	NR	TC,LC,PC,SJ
Iowa	3.5	PR,EC,MR	10000	WC	3500	25	None
Georgia	6	PR,MR	5000	MC,WC	3500	28	None
Missouri	3	PR	6000	MC,LM	4000	35	TC,LC,PC,SJ,EJ, RS,CS,CR
Kentucky	NR	PR,EC		MC	5000	10	None
Colorado	NR	PR,MR	5000	LM,WC	5000	16	TC,PC,SJ,EJ

LEGEND

PR= Prestressing reinforcement, EC= Epoxy-coated reinforcement, WWR=Welded wire reinforcement, MR=Uncoated mild reinforcement, LC= Longitudinal cracking, SJ= Seepage at panel joints, RS= Rust stains along tendons in panels, CR= Corrosion of prestressing reinforcement, MC= Moist curing, WC= Waterproof cover, LM=Liquid membrane curing, TC= Transverse cracking, PC= Panel cracking, EJ=Efflorescence at panel joints, CS=Concrete spalling at panel joints, NR= Not reported

Summary of PDP Experience in California and Other States

Table 1 summarizes PDP experience in California over the past 25 years as reported in the survey and sorted by bridge age (since installation of PDPs). It is evident that the majority of bridges using PDPs were on design-build projects, with the major incentive for speed of construction, or at railroad or water crossings, for which elimination of falsework was a major consideration. Although the design-build projects included multiple bridges using PDPs, the actual number of projects with PDPs after the SMHB project is quite small, with the majority being completed in the past 2 years or currently under construction.

Table 1 also shows that the PDPs used on these projects incorporated a deck thickness larger than that of SMHB, with most using thicknesses of 3.5 in to 4 in. After SMHP, most panels were pretensioned with black strand and included WWR, used a design compressive strength of 5000 psi and stand extensions of 3 in to 6 in, were supported by camber strips, and a CIP topping of 4000 psi concrete. Interestingly, many had issues in design, fabrication, and installation related to skews, constructability problems, and cracking in the CIP topping. These issues are addressed in a later section of this paper.

Table 2, adapted from a 2010 survey reported in Reference 16, provides a basis of comparison for PDPs in California bridges to those in 14 other states, many of which routinely use PDPs. California practice closely matches other states in panel thickness, reinforcement type, and panel and CIP topping design compressive strength. Although other states have a much more extensive history and usage of PDPs, California problems with cracking of the CIP topping are consistent with other states. Many of the listed problems for other states were tied to deck deterioration issues related to freeze thaw areas. Problems with skews were not widely reported by other states.

Reasons to Use PDPs

Survey participants were given a list of 7 reasons/advantages for using PDPs, as well as the option to include other reasons, and were asked to rank their top 5 choices (in some cases the top 3 were ranked). In addition, respondents could mark other reasons without ranking. Results are reported in Figure 8, which shows the ranked reasons for using PDPs, with the highest ranked reason (out of a score of 5 maximum) on top and the lowest on the bottom. Each bar provides additional information to help evaluate the significance of each ranking: the number who ranked each category (n_rank) as well as the total number of respondents who marked the reason without a score (n_tot). The percentage of respondents with PDP experience is also shown in parentheses.

As expected, increased speed, reduced falsework/formwork, and reduced onsite operations were the top reasons for using PDPs. At least 50% of those choosing these reasons had experience with PDPs. In contrast, many without experience (especially consultants) listed reduced cost as a top reason for using PDPs, although it may be difficult to discount this reason in view of the many design-build projects choosing to use PDPs for speed of construction, which can translate into reduced cost and increased profit. It may be of some

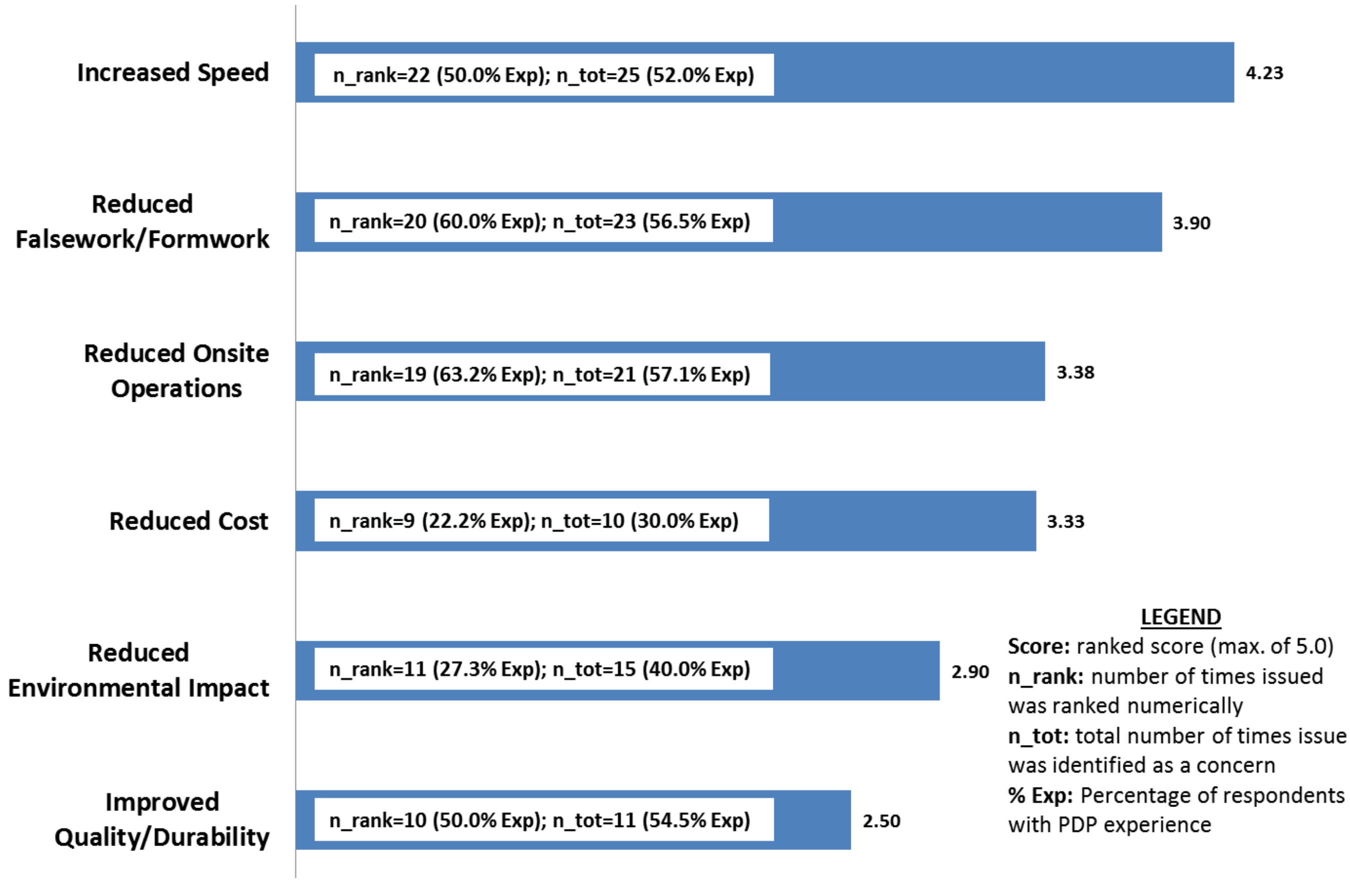


Figure 8. Ranked Reasons to Use PDPs (All Respondents)

concern that the lowest ranked reason was improved quality and durability. This may be related to the deck cracking issues that ranked highly in issues/concerns for PDPs. Additional analysis (not shown here) demonstrated that the distribution of those who ranked each category reasonably matched the overall distribution of respondents for each classification (precasters, consultants, Caltrans, and contractors), with the exception of reduced costs as previously noted.

Issues and Challenges in Using PDPs

Survey participants were also given a list of 28 potential issues with PDPs (or reasons not to use PDPs), as well as the option to include other issues, and were asked to rank the top 5 issues. In addition, respondents could mark other reasons without ranking. Results are shown in Figure 9.

Two of the top three issues were deck cracking, both reflective transverse cracks (Figure 3) and longitudinal cracks along the girder line. As reported by respondents (Table 1), such cracks developed in many projects. According to the 2010 national PDP survey, longitudinal and transverse (reflective) cracks in the CIP topping concrete on deck surface are "the most prominent deterioration problem reported" in PDP bridge decks.[16] Transverse cracks are

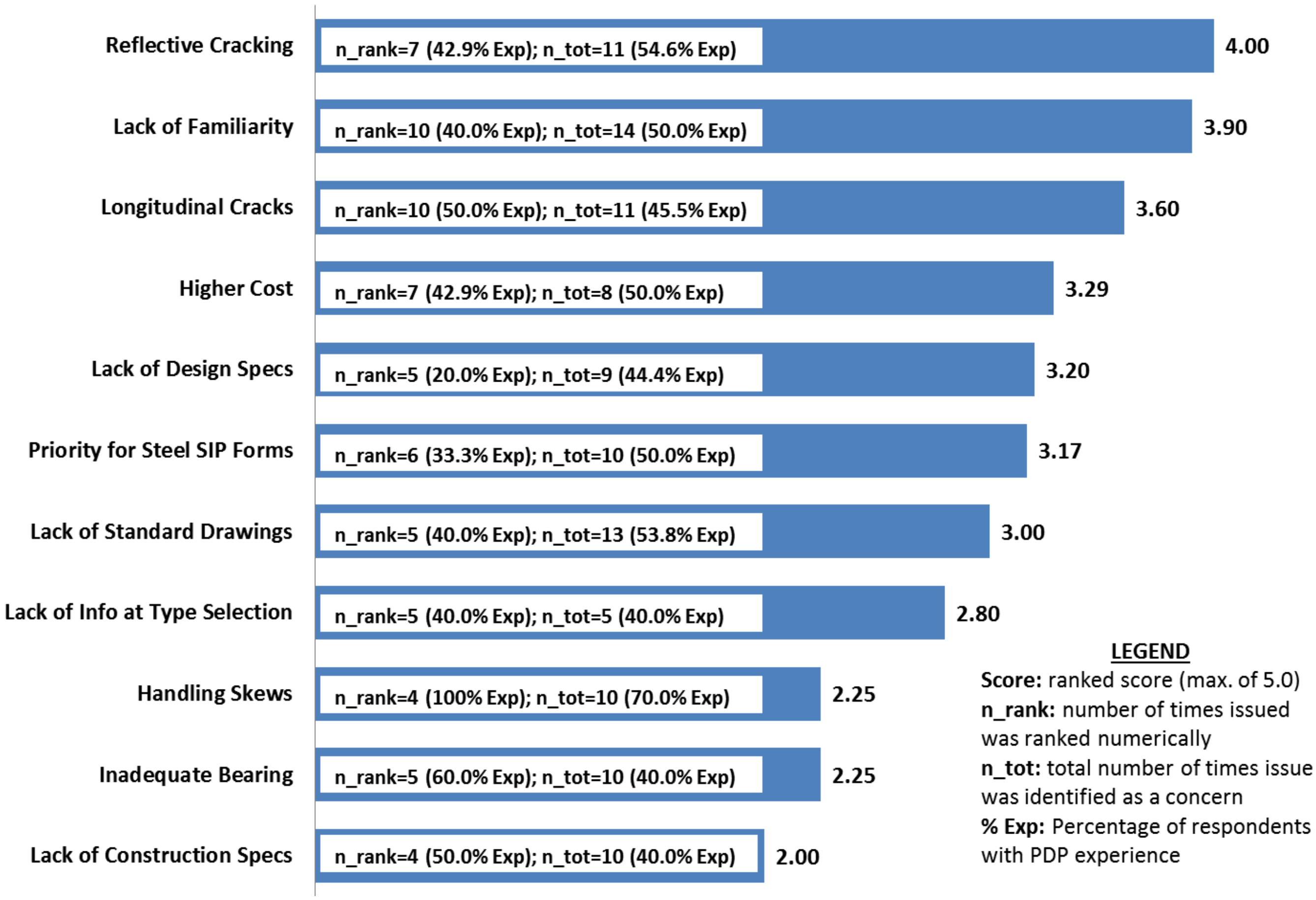


Figure 9. Ranked Issues in Using PDPs (All Respondents)

believed to develop in the deck above transverse joints between panels due to the concentration of shrinkage and creep strains in the CIP concrete at this location. Numerous authors have indicated that such cracks, which typically terminate partway through the CIP topping slab depth, do not affect the structural performance of the slab, but could become a pathway for moisture and chlorides in corrosive environments. [17,18] To minimize reflective cracking, some states restrict the use of PDPs to positive moment regions or increase the longitudinal reinforcement in negative moment regions, which has been shown to effectively serve as transverse crack control in the negative moment regions. Longitudinal cracks at the girder lines are considered structural cracks, often caused by negative moment over the girder supports and thus the stiffer performance of prestressed concrete girders compared to steel girders are believed to reduce the occurrence of such cracks. Although some research has shown that strand extensions need not be required, extensions do provide continuity at girders, where longitudinal cracks are likely to form. AASHTO LRFD C9.7.4.3.2 recognizes this by stating that, “The absence of extended reinforcement, however, may affect transverse load distribution due to a lack of positive moment continuity over the beams or may result in reflective cracking at the ends of the panel.” [19] Caltrans has applied methacrylate to bridge decks where transverse and longitudinal cracks appeared in the CIP topping slab.

It is noteworthy that lack of familiarity was ranked as the second highest issue associated with using PDPs in California. The full description in the survey was "Lack of prior use/familiarity in California bridges". This is likely related to other issues such as higher cost. Through greater use, the bridge community will gain experience, reduce problems, and develop more cost-effective and time-saving practices.

Several of the remaining issues—lack of design specifications, standard drawings, and construction specifications, as well as priority of SIPMFs and lack of confidence/information at Type Selection—were ranked not only in this question but addressed repeatedly in the survey through comments and suggestions for improvement. These issues are directly addressed through the "Approach to reestablish use of PDPs for ABC in California" (and Table 5 under Recommendations). It is acknowledged that there is a need for the timely development of such a comprehensive package.

Finally, although concern over skews was ranked only 9th on the list, it was selected by the highest percentage of respondents with experience (70%). Undoubtedly, this is due to actual troubleshooting required during projects and therefore is considered a significant issue to be addressed. Other states have also dealt with skew issues and developed solutions that should be considered.

Problems/Issues, Mitigation, and Suggested Improvements

Survey participants with PDP experience reported specific problems or issues of concern that arose in the implementation of PDPs. In some cases, mitigation measures were also given. Table 3 provides a summary of issues, which have been grouped together from all respondents into the following categories: Epoxy-coated strand, Skews, Design, Fabrication, Placement, Camber strips, Cracks in CIP topping, Field conflicts, and Field miscellaneous. These tables provide a detailed understanding not only of the problems that may arise in implementing PDPs, but also of the approaches taken to resolve the issues.

Table 4, Suggested Improvements, provides a summary of suggested improvements to PDP systems, categorized by classification (precaster, consultant, Caltrans, Contractor). This allows the reader to understand specific ideas within each stakeholder group. Figure 10, a Caltrans draft XS Sheet for PDPs, is provided as an example of the ongoing development of key documents for PDPs, which will benefit from survey results.

Table 3. Problems/Issues and Mitigation

Topic/Issue	Respondent	Problems/Issues	Mitigation during Project
Epoxy-coated Strand	Precaster	PDP cracking occurred due to combination of short transfer length of epoxy-coated strand (and large splitting stresses) and addition of silica fume to mix.	None stated. NOTE: internal deck panel test program was conducted.
	Caltrans	For 3.19 in thick panels and epoxy-coated prestress strands with impregnated grit, cracks were observed and causes were believed to be related to one or more of the following: handling at precast yard, inconsistent curing, improper methods employed during casting, poor hot weather methods, inconsistent mix, handling in the field, improper dunnage used to support panels (away from hold down points), and lifting panels at one point. Contractor's Position: design problem; State Position: improper handling. State lost in DRB hearing.	Attempts at resolution: additional mild reinforcing steel placed adjacent to prestressing strands; revised handling methods; debonding strands at the edge of the panels; use of additional strands and less P/S force. However, no clear solution was determined.
	Caltrans	For Freeze Thaw area application, unusually thick deck (5-in panel and 4 5/8 in CIP topping) was used, to satisfy interpretation of AASHTO LRFD requirements.	None stated.
Skew	Precaster	Panel cracking occurred during handling due to non-rectangular skewed pretensioned panels.	1. Replaced PS strand with rebar. 2. Added edge reinforcement.
	Caltrans	Several "skewed panels" demonstrated full depth cracks on side of skew, likely attributed to elastic shortening of short strand and insufficient development length during detensioning. Panels were rejected. These panels were also missing mild steel reinforcement along skewed edge for crack control.	1. Replaced short lengths of strand in skewed panels with mild reinforcement. Detailed mild reinforcement parallel to skewed edge for additional stiffness, crack control purposes. 2. Released strands for non-rectangular panel simultaneously to avoid cracking
	Caltrans	Difficulty existed in handling skews in design, fabrication, and construction, including forming at end of spans and rebar details for corners of deck panel. For short panel span, mild steel was used, but longer span panels with strand and high skews require detail to reinforce sharp panel corners with only mild steel.	None stated.
Design	Caltrans	Design-build submittal included PDP with PS strand and WWR placed above mid-depth.	Design was revised to place strand at middepth.
Fabrication	Precaster	Panel cracking for first two panels at each end of casting bed during detensioning process.	#3 bars transverse to PS strands were added at panel ends to limit effects of splitting cracks during detensioning (first two panels at each end only).
PDP Placement	Caltrans	For Caltrans I girders used with PDP, only a small gap was produced between bottom of the ends of hooked girder stirrups (extending into deck) and top face of thick PDP's. This created problem for placement of longitudinal continuous bars intended to be placed under horizontal legs and on top of PDP's.	None stated.

Table 3. Problems/Issues and Mitigation (Continued)

Topic/Issue	Respondent	Problems/Issues	Mitigation during Project
PDP Placement	Precaster, Caltrans	Difficulty in panel placement due to conflict of stirrups with PDP bearings, for typical I-girder end block detail.	Terminated end block stirrups below top of girder and placed supplemental horizontal shear rebar at girder centerline.
Camber Strips	Caltrans	Tall camber strips (i.e., several inches) appeared to be potentially unstable during panel placement, causing concern during placement and for subsequent CIP deck pour.	Glue was placed on both interfaces between camber strip and girder and between camber strip deck panel to stabilize PDP and prevent toppling during placement of PDP. This worked because “tack time” for glue was sufficient to adjust PDP as needed during placement.
	Consultant	Polystyrene camber (bedding) strips did not always adhere readily at interface between girder and camber strip and tended to break away, allowing leakage of paste from CIP deck concrete onto sides of supporting girders.	Sandblasting was used to remove cement residue from girders.
	Caltrans	Cross slopes larger than 6% led to problems during panel placement, including instability of camber strips and concern over sliding of panels.	None stated.
	Caltrans	Potential voids under PDP leading to inadequate bearing between PDP and girder, due to inadequate gap between PDP and top of girder when short height camber strips are used. Despite requirement for minimum 1 in clearance, in some cases camber strip was less than 1 in before deck pour, potentially preventing CIP deck concrete (with 3/4 in maximum coarse aggregate) to adequately flow under panel.	High strength grout was placed between forms that were added (before placement of deck steel), to ensure adequate bearing. This extra field operation worked.
	Caltrans	After removal of camber strip, air voids were observed in CIP bedding layer supporting PDP’s.	Gaps in camber strips were required to inspect concrete.
	Caltrans	Steel angles were preferred for supporting PDP’s.	Contractor used polystyrene camber strips, for speed of construction and to avoid field welding.
Cracks in CIP Topping	Consultant	CIP deck experienced high crack density, but it did not appear to be reflective cracking; the reason could not be positively identified, resulting in debate over responsibility for crack repair.	Methacrylate was used to mitigate deck cracking.
	Caltrans	Reflective transverse cracking and longitudinal cracking were not observed. However, with increase in use of fly ash percentage in CIP topping mix, more deck cracking due to shrinkage has been observed, unless curing is done very well.	Caltrans typically places Methacrylate to rehabilitate decks (even if new), to increase lifespan. Caltrans is also exploring effectiveness of polypropylene fibers through research and practice.

Table 3. Problems/Issues and Mitigation (Continued)

Topic/Issue	Respondent	Problems/Issues	Mitigation during Project
Cracks in CIP Topping	Caltrans	Deck cracking of unknown nature. Deck surface cracks were noticed 3-4 weeks after initial casting of the deck. Cracks ran longitudinal with bridge and varied in length and width. Distinct pattern from frame to frame. Cracking along girder/panel lines. Grew in intensity over time.	No effect from changes made in Contractor's operations. PDP design should be revisited. Applied methacrylate to entire surface of new bridge deck.
	Caltrans	Cracking on top deck due to uneven settlement between top of girders and bottom of precast deck panel.	Used methacrylate resin to seal cracks on top deck.
	Caltrans	Reflective cracking at PDP edges was observed.	Inspection performed but no repair approach stated.
	Precaster, Caltrans	Fit and cover within CIP topping thickness for mechanical bar splices used for negative moment reinforcing because contractors often prefer large body couplers with shear-off set pins. Providing code-required top cover over coupler required coupler and top deck rebar to be placed directly on PDP's (without concrete flowing beneath).	Design-build team recommended to: 1) Place splices away from bent cap, where maximum negative moment occurs. 2) Place larger bars (e.g., #11's) in deck above I girder between stirrup legs (to avoid placing larger directly on PDP's).
Field Conflicts: Keyway	Consultant	Flush keyway detail (proposed by precaster) had thin edge, prone to breakage during precast form stripping and during handling, leading to rejection of some panels. (Note: this approach was preferred over Caltrans' past approach of hanging formwork below a gapped joint.)	Broken keyways required repair or full panel replacement.
Strand Extensions	Consultant	Often prestress strand extensions conflicted with stirrups extending out of girders. This was an inconvenience as panels were being placed quickly at night and bars could not simply be bent out of the way (due to epoxy coating).	None stated.
Rebar Extensions	Consultant	Extensions of mild steel across diaphragms tended to conflict because they were perfectly aligned.	None stated.
Field Misc.	Caltrans	Contractor requested to cut panels.	Caltrans did not permit cutting panels.
	Caltrans	PDP's were eliminated at any deck span that supported utilities below, because Caltrans did allow field drilling through PDP's for utility hangers. Aligning holes in PDP for future utility is difficult. Deck spans supporting utilities were constructed as conventional full depth CIP (with the exception of one widening where formed holes were provided per a layout provided by the Contractor).	It is recommended not to use PDP's when supporting utilities.
	Caltrans	Contractor with limited experience installed supplemental, temporary working platform as fall protection while placing PDP's, reducing speed of construction (installation of temporary platform, placement of PDP's, and removal of platform).	

Table 4. Suggested Improvements

Topics/Issues	Respondent	Comment
Standard details; Selection; Literature	PC	Add weighted factor for speed of construction and enhanced safety performance in determining deck system. Develop standardize details. Study best practices and lessons from other DOT's. Compare construction cycle for PDPs to CIP.
Skew		Eliminate prestressing strand for skewed panels.
Standard details		Update XS sheets for PDPs. Familiarize CA design and construction community with PDP practices from other states.
Application		Be cautious in use of PDPs for non-parallel girder lines because each panel becomes a unique wedge shape.
Skew; Camber Strip	Consultant	Develop standard approach for skewed supports. Develop standard leak-resistant specification for bedding strips.
Literature; Application; Skew		Research available literature, standards, and maintenance reports from other DOT's (TxDOT, WSDOT, TNDOT, etc.). Combine most proven details and design approaches. For railroad, PDPs minimize formwork, allow easy access from above instead of beneath, but required additional lane/bridge closures to allow for small crane to be set in adjacent lane. Consider skewed supports: cumbersome to place CIP concrete full depth in triangular regions.
Seismic testing		Test composite system subjected to seismic loads, including integrity of horizontal diaphragm, potential loss of composite action with CIP, points of connection to girders, and adverse accumulated effects from series of moderate EQ or long term traffic loads (loosening of connection) that may reduce capacity for subsequent MCE event.
Dissemination		Present results of projects using PDPs to Caltrans/design-builders. Provide wider distribution of PCI best practices.
Dissemination; Design guidance; Standard details		Improve designer familiarity. Update MTD 8-6. Updated guidance will help designers realize this is still an option and how to design specify. Provide standard designs like for deck slabs in MTD 10-20.
Caltrans Support; Selection; Dissemination		Acquire support/Caltrans buy-off, which is most important. Develop Authorized Materials List and MTD for design/use. Explain advantages over SIPMFs. Distribute research.
Durability; Cracking; Standard details, Design		Test to determine/demonstrate long-term durability. Develop details to minimize reflective cracking at panel joints. Develop standard details and guide specs for design implementation.
Selection; Construction specifications; Standard details		Determine if cost for PDPs is lower than SIPMFs. Develop guidance to prevent more opportunities for contractor to make mistakes or do work poorly. Develop standard detailing that is proven to minimize complexity and offer robust installation method.
Design		Address Negative Moment region, especially if superstructure is not PS.

Table 4. Suggested Improvements (Continued)

Topic/Issue	Respondent	Comment
Standard details; Selection	Consultant	Provide a practical system and/or proof that it will work well in a specific situation. Develop consensus at Caltrans on details that work best. Establish if PDP is most cost effective: panel cost would likely be acceptable, given deck cost relative to overall project cost. But additional cost beyond that of SIPMF should be justified by overall benefits.
Standard details; Application	Caltrans	Provide standard details to prevent cracking and resolve deck smoothness. Include lifting point details as standard. Investigate use of lightweight concrete to reduce crane loads.
Standard details; Design guidance		Develop acceptance criteria for roughen top surface of PDPs (bond between PDP and CIP topping) to eliminate shear connectors. Design PDPs for construction load as part of designer's calculation.
Skew; Design guidance		Develop details for standard XS sheets for case of high skews, including PS strand. Develop table for XS sheet with variables: span range, rebar or PS strand, with details for span. For shorter spans, PS strand may not be required.
Construction Specifications; Acceptance criteria; Skew		Provide construction specifications Establish requirements for rejection of panels in the field. Improve detailing of reinforcement and strands, especially for skewed ends of panels, to account for lack of strand development length and probability of cracking.
Specifications; Selection		Develop documents and means for PDPs to be considered in design. Determine speed of construction vs. other deck construction because CIP topping goes against ABC, compared to full depth PC panel systems.
Specifications		Develop Specs and Standard plans, including construction tolerances.
Specifications, including materials; Dissemination		Develop Design guidelines (MTD, XS sheets, Bridge Design Practices) for California. Standard details and design procedure will help bridge engineers, especially consultants, feel more comfortable in using PDP. Reduce or eliminate difference in concrete age and compressive strength at construction stage. Materials/concrete mix should be similar as well. Provide training and implement outreach program to bridge engineers with latest developments for PDPs. Share successfully constructed projects.
PDP Support; Specifications		Allow option for steel supports instead of camber strips. Define tolerances for girder cambers/storage.
Standard details; Skew; Design guidance		Develop improved detailing of reinforcement and strands, especially in skewed ends of panels to account for lack of strand development length and probability of cracking. Provide adequate thickness of PDPs to account for stresses developed during detensioning and handling within 24 hours of concrete placement. Apply lessons learned from San Mateo-Hayward Widening project.
Selection		Highlight PDP improved appearance (comparing to SIPMF which rust) and being less susceptible to corrosion of deck rebar; improved durability. Precast construction is preferred over CIP construction in freeze-thaw regions, such as in the high mountain areas where salt is frequently used. PDPs are good alternative for bridges over railroads because railroads give very stringent requirements and tight windows for construction.
Selection	Contractor	Compare costs for casting PDPs onsite vs. hauling PDPs, including variables of distance and size of project. Compare PDP cost to SIPMF and wood forming system.

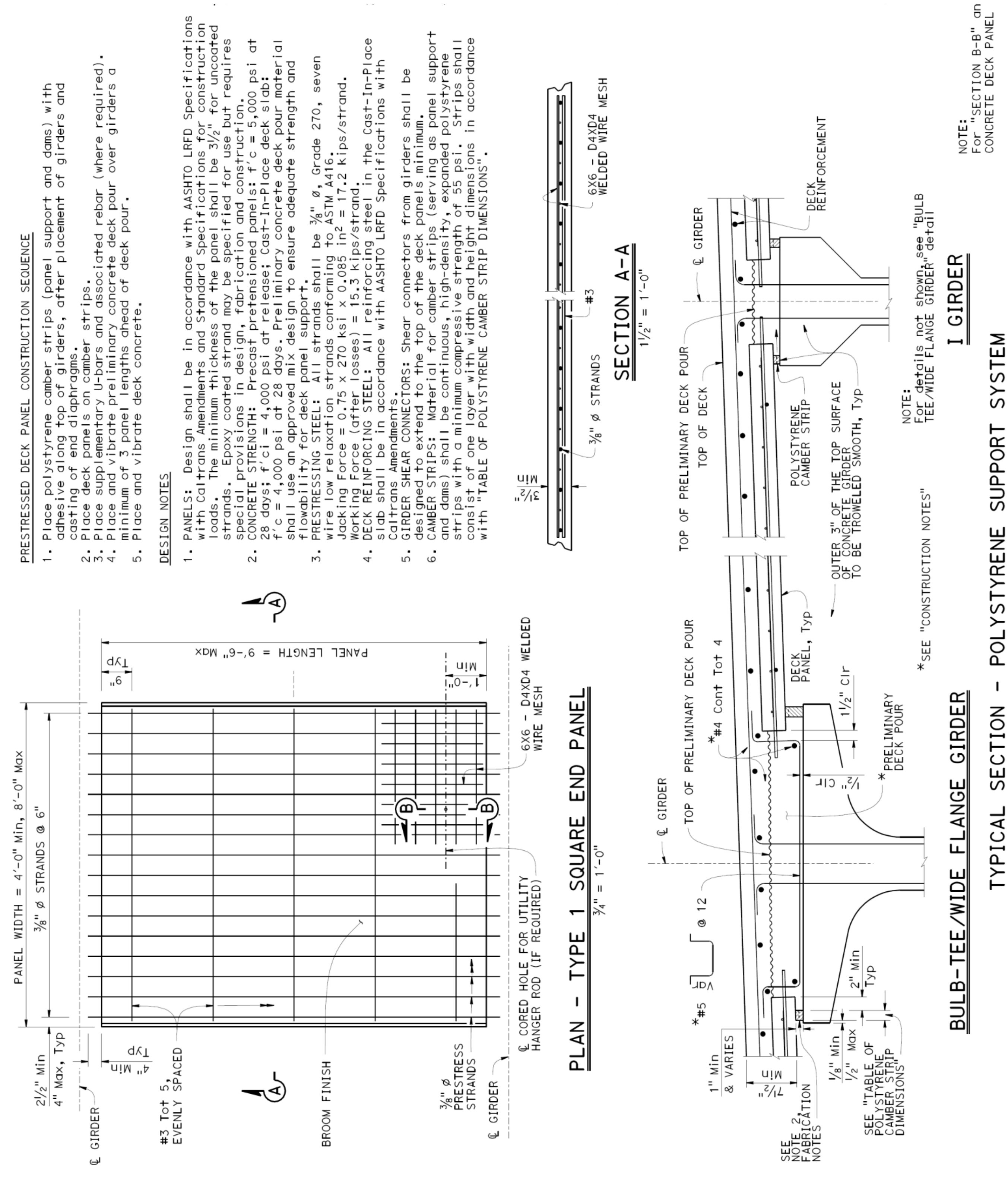


Figure 10. Caltrans Draft XS Sheet for PDPs

RECOMMENDATIONS FOR IMPROVED DETAILS AND GUIDELINES

Based on Tables 3 and 4, comprehensive recommendations for improved details and guidelines have been developed, as shown in Table 5.

Table 5. Recommendations for Improved Details and Guidelines

Topic/Issue	Recommendations
Essential Bridge Practice Documents	1. Develop updated MTD 8-6 for design guidance 2. Develop new Bridge Design Practice with design examples 3. Develop new Bridge Design Aids with design tables for pretensioned and reinforced concrete PDPs, based on panel span, panel thickness, reinforcement type (strand, rebar) and spacing, similar to MTD 10-20 4. Develop updated Bridge Standard Detail Sheets (XS Sheets), with Background Form and Notes 5. Develop/update Standard Specifications, with detailed notes
Study of Best Practices	1. Research available literature as well as standards and maintenance reports from DOT's. Contact select DOT's to discuss issues and best practices. 2. Collect best practices from recent California bridges using PDPs.
Dissemination	1. Prepare Caltrans approved documentation and presentation for dissemination to bridge community, addressing design, fabrication, construction, and successful practices. Disseminate in wide range of venues. 2. Provide training and implement outreach program to bridge engineers.
Selection Criteria	1. Develop design guidance as basis for Type Selection, comparing PDP and SIPMF systems (and possibly full-depth precast deck panels), costs, and identifying cases for which PDPs are most applicable (e.g., water/railroad crossings, ABC conditions, freeze thaw areas), and not applicable (e.g., non-parallel girders). 2. Ensure ABC criteria are addressed, including speed of construction and enhanced safety. 3. Compare costs for casting PDPs onsite vs. hauling PDPs, including variables of distance and size of project.
Design (General)	1. Incorporate basis for assumption of composite action between panel and CIP topping within MTD that eliminate shear connectors. 2. Require placement of strand at middepth. 3. Determine if lightweight concrete is feasible/economical for PDPs. 4. Ensure standard design and design tables address construction loads and cases for which pretensioning is not required. 5. Establish impact of different concrete strengths and ages for PDPs and CIP topping. 6. Consider need for testing to verify integrity of horizontal diaphragm, potential loss or composite action, and connections to girders. 7. Ensure design/construction is clear for negative moment regions. 8. Determine if thin keyway detail is susceptible to cracking during stripping and handling.
Standard Details	1. Ensure PDP surface roughening is clearly established in XS Sheets. 2. Include lifting point details. 3. Ensure standard for strand extension is sufficient to prevent longitudinal cracking.

Table 5. Recommendations for Improved Details and Guidelines (Continued)

Topic/Issue	Recommendations
Construction Specifications	1. Establish updated requirements for rejection of panels at the plant and in the field. 2. Establish construction tolerances, including girder camber in the plant and field.
Epoxy Coated Strand	1. Add requirement in MTD and Standard Specifications to test epoxy-coated strand to ensure parameters associated with potential PDP cracking is isolated, including design, fabrication, handling, and installation issues and development of project-specific specifications. Areas to address must include: transfer and development lengths for grit-impregnation consistent with bare strands; limitations on shrinkage-increasing mineral admixtures; and PDP thickness. 2. Add guidance in MTD for application of PDPs in Freeze Thaw areas. Reevaluate Caltrans and AASHTO LRFD requirements for cover over reinforcement in PDP and CIP topping. 3. Review the literature on testing and use of epoxy-coated strands in PDPs. Conduct needed research to allow epoxy-coated strands to be an option for Freeze Thaw areas.
Skews	1. Conduct study, including review of practices in other states, to identify cases for which skews require special detailing, as RC panel (eliminating prestress), prestressed panel, or CIP pour. 2. Develop design approaches and standard approach for skewed panels and add provisions to MTD and examples in BDP. 3. Add skew details (reinforced and prestressed), including mild reinforcement parallel to skewed edge, to Caltrans XS Sheets for PDP. 4. Ensure skew details address strand or rebar development.
Fabrication	1. Address potential splitting during detensioning and need for transverse rebar at panel ends to limit effects.
PDP Field Placement	1. Add note on XS sheet and/or note in MTD to specify minimum gap in between bottom of stirrup after (field) hooking and top of PDP. 2. Add detail to XS sheet and/or note in MTD to terminate end block stirrups below top of girder and place supplemental horizontal shear reinforcement at girder centerline. 3. Add note to MTD to distribute large negative moment rebar above girder between stirrup legs or to use a larger number of smaller diameter bars. 4. Add explicit requirement for CIP topping thickness and detailing to be sufficient for code-required cover and concrete flow between deck reinforcement and PDP. Add note to MTD to relocate splicing/couplers away from bent cap (maximum negative moment location) if suitable cover cannot be economically achieved. Address tolerances and consideration of coupler sizes in this requirement. 5. Determine if steel supports (rather than camber strips) for PDP is a viable option. 6. Develop XS sheet details and permissible construction loads to address the use of the new California Wide Flange girder with precast deck panels.

Table 5. Recommendations for Improved Details and Guidelines (Continued)

Topic/Issue	Recommendations
Camber Strips	1. Limit use of PDP's to bridges with cross slope no larger than 6%. Include limitation on XS Sheet and MTD. 2. Require use of glue on both PDP interfaces (girder and PDP) to ensure stability during placement of PDP and during subsequent CIP deck pour, and to prevent potential leakage of paste. 3. Specify minimum clearance of 1 in under PDP to ensure adequate bearing and to avoid extra field grouting operation. Add inspection requirement to specifications. 4. Require slots in camber strips for inspection of bedding layer CIP concrete. Add to XS sheet detailing.
Field Conflicts	1. Add note in MTD and XS Sheet Background Notes regarding types of potential strand/bar conflicts in field (e.g., strand extension-stirrup, rebar extensions at diaphragm) and steps to take to avoid conflicts.
Cracks in CIP Topping	1. Develop details for use of PDPs that minimize or prevent reflective cracking at panel joints. Indicate cases and locations for which reflective cracking is more likely. 2. Develop list of approaches for repairing deck cracks, including use of methacrylate.
Field Operations	1. Add notes to PDP background to explain various functions of PDP's, including serving as work platform. 2. Add guidelines to MTD to prevent use of PDP's for locations where utilities must be supported. Develop alternative panel design to support utilities.

CONCLUSIONS

Although California is still in formative stages in adopting PDPs due to challenges encountered in the past, Caltrans has recognized that precast systems can be an integral part of an ABC solution. PDPs have proven to be an important approach for PBES in many states around the country. Based on the Fall 2014 survey of the California bridge community, it was found that the majority of California bridges using PDPs in the past 25 years have been on design-build projects, or at railroad or water crossings. Although the number of bridge projects with PDPs after the SMHB project has been small, within the past 2 years an increasing number of projects have used PDPs due to their benefits. There is a growing interest within California to use PDPs more regularly as a bridge construction solution.

Survey results also indicate that the bridge community is very interested in the development of comprehensive design and construction documents such as those listed in Table 5 under "Essential Bridge Practice Documents" to ensure successful implementation of PDPs. In addition, the bridge community has provided extensive feedback, which has been synthesized into 48 specific recommendations in 15 categories. This is expected to provide an important basis for the further development of documents critical to PDP implementation. To its credit, Caltrans has already begun the process of developing some of these documents. This suggests that conditions are becoming ripe for significant advances in PBES, including PDPs, for ABC in California.

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