Precast Concrete Design-Construction of San Mateo-Hayward Bridge Widening Project

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In recent years, the California Department of Transportation (CALTRANS) has developed innovative precast concrete connection systems for application in high seismic regions, including the San Mateo-Hayward Bridge site. The award-winning San Mateo-Hayward Bridge Widening Project is a 4.9 mile (7.9 km) twinning of an existing 30-year-old bridge in an active seismic area and over the environmentally sensitive San Francisco Bay. The only viable solution was an all-precast concrete substructure and superstructure consisting of driven cylinder piles, bent cap shells, bulb-tee girders, and stay-in-place deck panels. A 125-year service life was ensured through the use of epoxy-coated reinforcement, a high-pozzolan concrete mixture, and an extensive polyurea coating. Bridge construction advanced without falsework and within the existing right-of-way on a temporary work trestle. This article describes the design, production, and erection challenges, as well as the decisive advantages of precast concrete construction in environmentally sensitive and earthquake-prone regions.

Built in the late 1920s and partially reconstructed in the 1970s, the San Mateo-Hayward Bridge served as a vital transportation link on U.S. Highway 92 between the cities of Hayward and San Mateo, California, a major commuter route from the East Bay area into San Francisco (see Figs. 1 and 2). The bridge supported two lanes of traffic in each direction with a par-

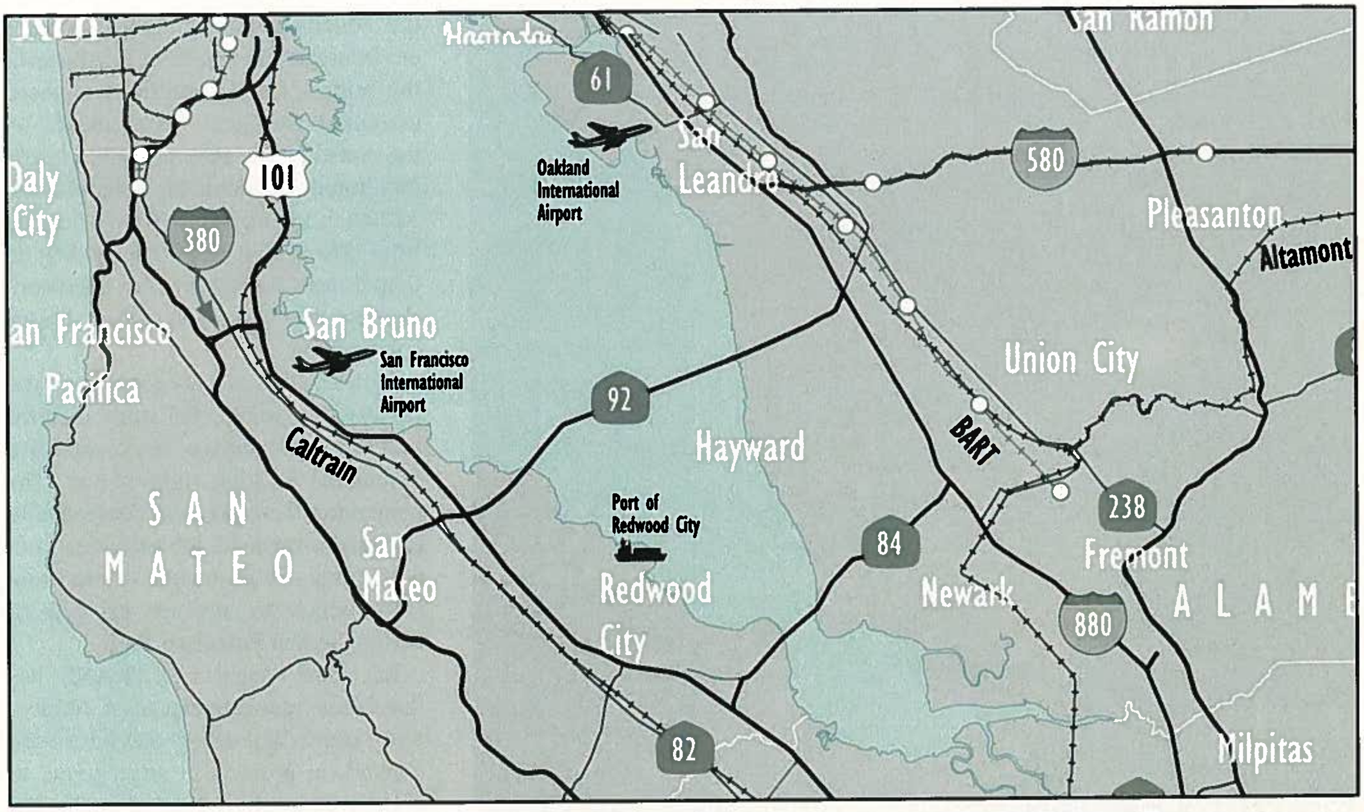

Fig. 1. Site map of the San Mateo-Hayward, California, area shows the bridge location over the San Francisco Bay.

tial shoulder for stalled or emergency vehicles and accommodated a daily average of 81,000 vehicles. During peak traffic hours, cars and trucks were typically bumper to bumper in both directions over the entire 7.5 mile (12 km) length of the bridge.

It was clear to both the California Department of Transportation (CALTRANS), headquartered in Sacramento, and the local municipal governments of Hayward and San Mateo that the very challenging task of twinning the existing bridge was the only way to resolve the escalating traffic congestion problem without recourse to interruption of traffic or bridge closure. In the early 1990s, CALTRANS conducted a feasibility study to find a rapid and economical solution for constructing a twin structure over the environmentally sensitive San Francisco Bay. CALTRANS decided to build a new bridge parallel to the existing bridge to increase the roadway capacity from four to six lanes with two emergency shoulders (see Fig. 3).

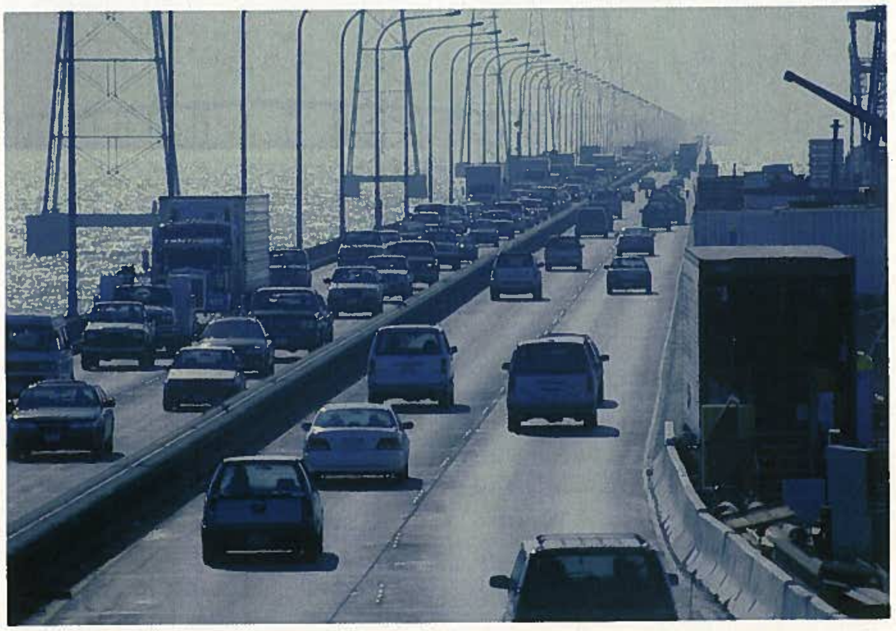

Fig. 2. Existing San Mateo-Hayward Bridge was constructed in 1927, with two lanes of traffic in each direction. (Courtesy of CALTRANS District 4 Photography Department)

Conventional cast-in-place (CIP) construction and its inherent need for extensive falsework was not a viable option due to the potential for adverse ecological impacts of formwork and shoring supports on the fragile and shallow marine environment. Rather, an "over the top" erection technique was required to keep construction out of—and above—the bay waters. Precluded from using normal marine construction equipment at the site, an over-the-top erection technique could only be accomplished using a temporary moveable, self-supporting erection platform or work trestle.

It is important to note that in California's bridge design and construction history, the use of precast concrete for superstructures has lagged behind the predominant use of CIP concrete solu-

Fig. 3. Construction under way with temporary work platform adjacent to the existing bridge. Barge delivery of precast concrete components and a movable work trestle allowed traffic to flow uninterrupted on the old bridge. (Courtesy of Balfour Beatty Construction)

tions. The CALTRANS preference for CIP design was due primarily to the lack of research and uncertainty associated with seismic performance and design methods of precast concrete systems, especially with respect to connection design in California's many earthquake-prone areas.

Without adequate research support and design experience, most California bridge engineers were understandably reluctant to work with precast concrete designs and, likewise, the state's bridge contractors had less experience and cost incentives to use precast, prestressed concrete. Therefore, the San Mateo-Hayward Bridge Widening Project is significant in that it is the first project of its kind to use such a wide variety of prefabricated concrete products. In fact, this precast concrete project is the largest one in California to date, based on cost (approximately $138 million).

The 2004 FHWA/AASHTO International Scan on Prefabricated Bridges[1] validates the use of innovative prefabricated bridge elements in the United States (see Research Recommendations and Conclusions). A first in California for a bridge project of this magnitude, the San Mateo-Hayward Bridge Widening Project was designed using all-precast, prestressed concrete components from top to bottom.

THREE BRIDGE SYSTEMS CONSIDERED

Specific construction methods were needed to build the twin structure without adversely impacting the shallow, environmentally sensitive bay beneath the bridge. Local authorities imposed extremely stringent requirements on the construction activities and closely monitored the contractor's compliance. Although the bay is shallow—ranging from zero to 15 ft (4.6 m) depending on tidal flows—no falsework or formwork shoring was permitted during bridge construction.

Further, the assessments from the project's environmental study dictated that the new bridge be constructed within the existing right-of-way. The contractor, therefore, was compelled to plan and execute all job activities from a temporary work trestle, or platform, from which to advance bridgework across the San Francisco Bay.

In recent years, CALTRANS has developed innovative precast connection systems and details that have been applied on projects in areas prone to high seismic activity, including the San Mateo-Hayward Bridge site. After several years of study, CALTRANS (the owner) designed the 4.9 mile (7.9 km) bridge-trestle twinning structure in-house and developed three alternates for contractual bidding.

The three critical requirements for the selection of alternative bridge systems were: minimal adverse environmental impact, brevity of overall project duration, and a total in-place cost not to exceed $73 per sq ft ($786/m^2). CALTRANS considered three materials for the bridge widening project—structural steel, CIP concrete, and precast, prestressed concrete. After thorough design evaluation and review, the owner produced three total-precast concrete systems, considering the viable options for both seismic and nonseismic application.

Each of the three bridge design options had a common substructure scheme but varied in the superstructure (span and deck) elements. Specifically, CALTRANS' biddable alternatives included the following precast concrete configurations:

Alternative 1:

- Precast, prestressed double tees with spans of 60 ft (18.3 m);
- Precast concrete pier cap shells; and
- 42 in. (1067 mm) diameter

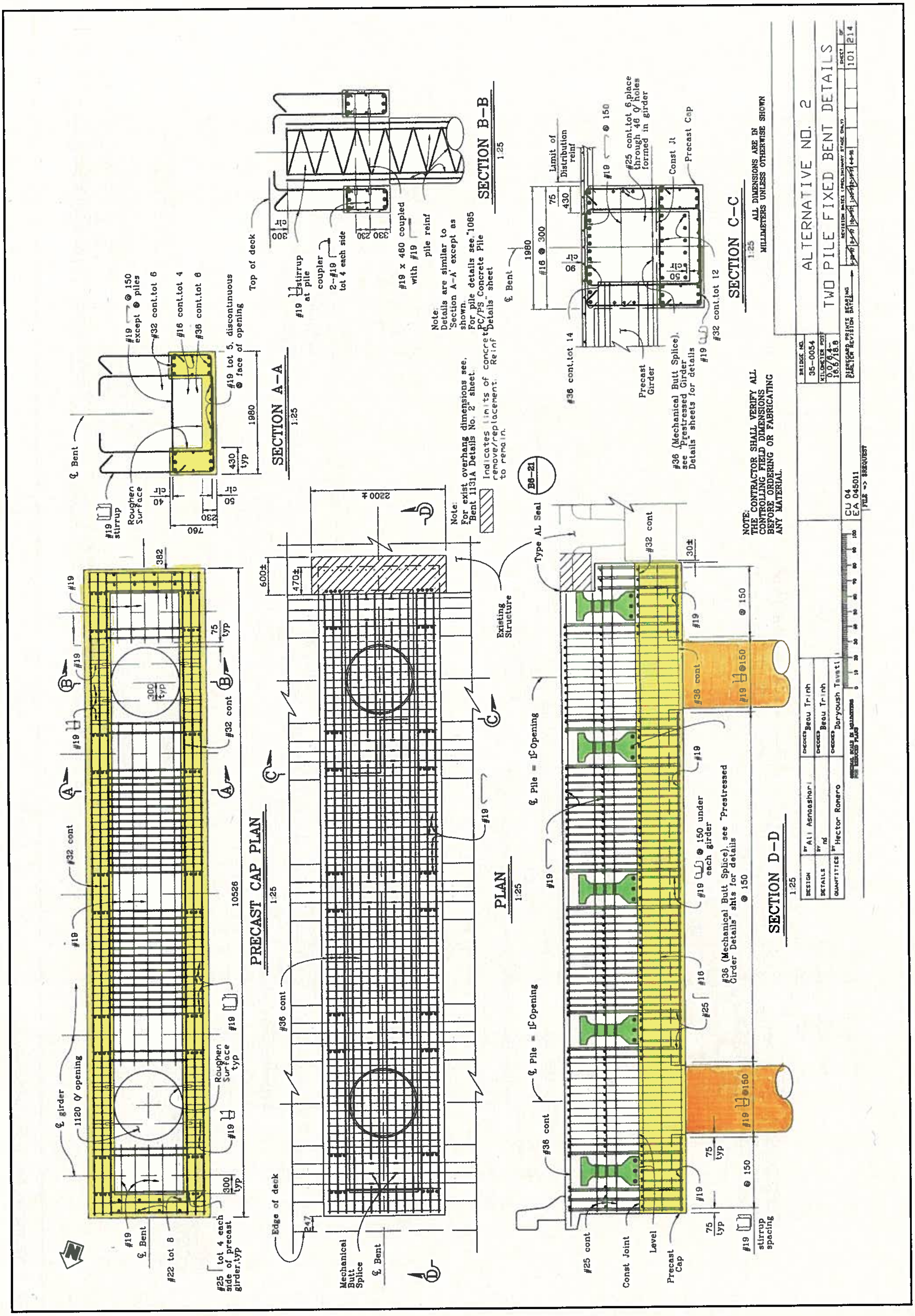

Fig. 4. Alternative No. 2: Two-pile fixed bent details.

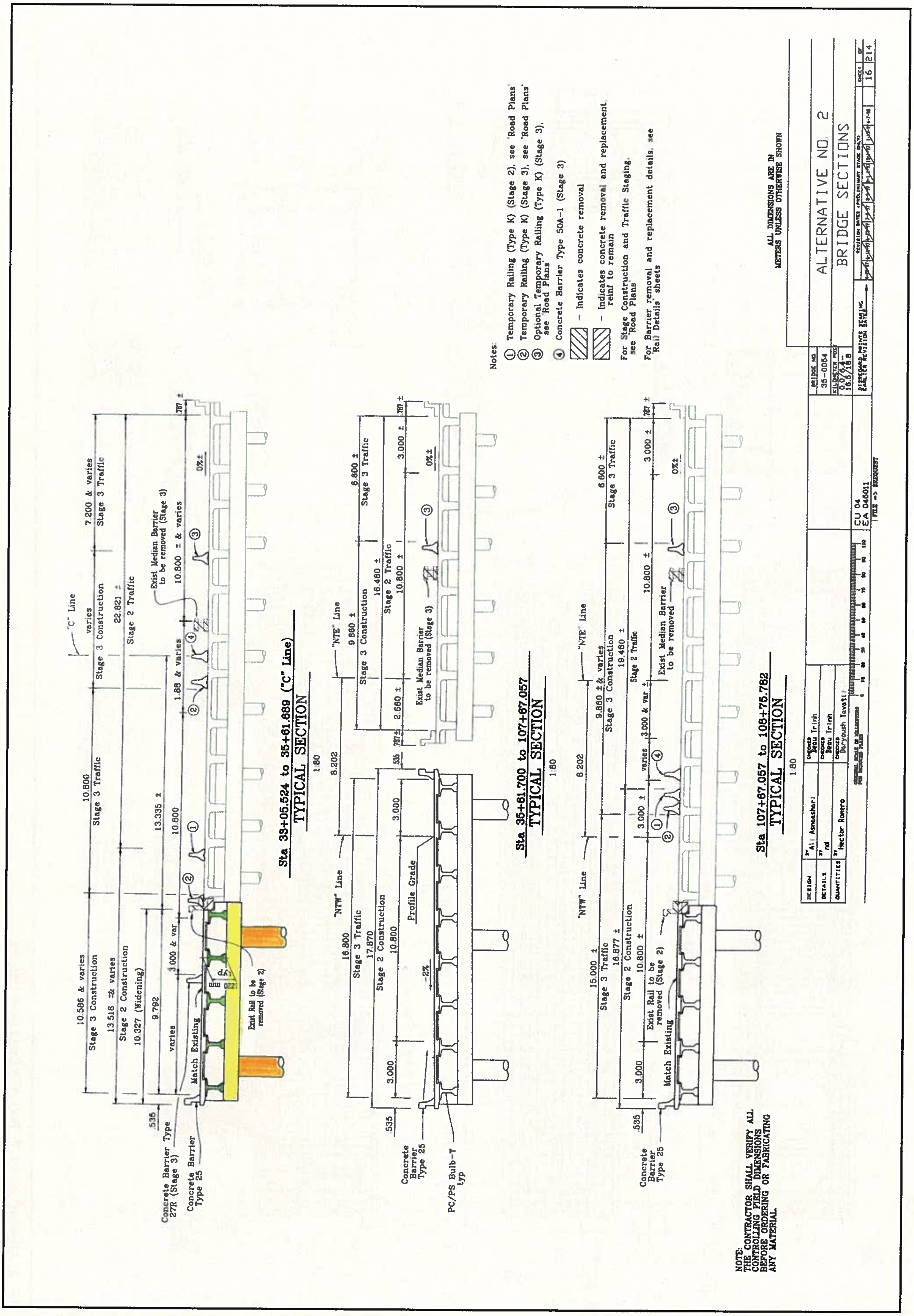

Fig. 5. Alternative No. 2: Bridge sections.

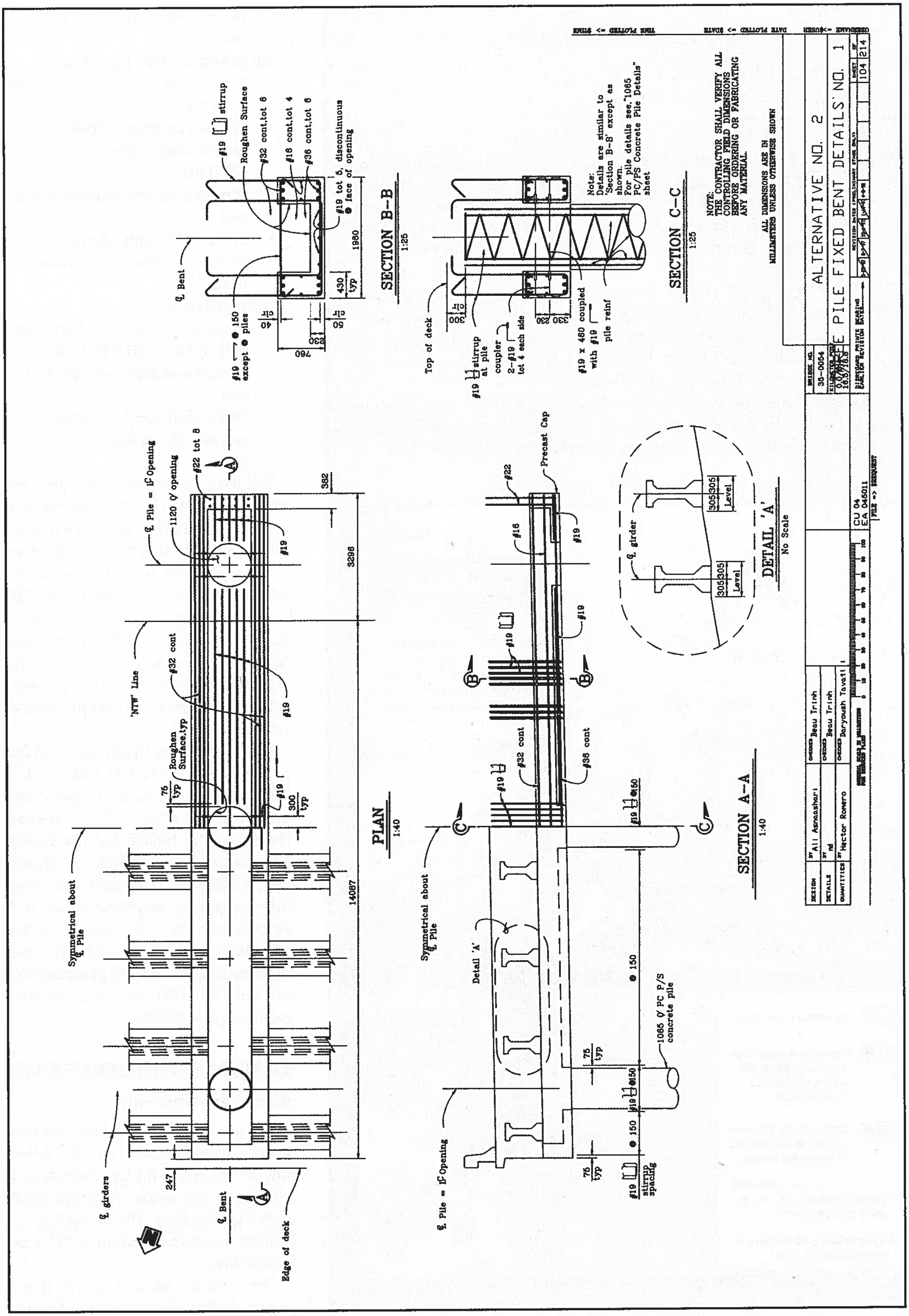

Fig. 6. Alternative No. 2: Three-pile fixed bent details.

precast, prestressed cylinder piles.

Alternative 2 (see Figs. 4 to 6):

- Precast, prestressed partial-depth deck panels;
- Precast, prestressed bulb-tee girders with spans of 90 ft (27.4 m);
- Precast concrete pier cap shells; and
- 42 in. (1067 mm) diameter precast, prestressed cylinder piles.

Alternative 3:

- Precast, prestressed voided slabs with spans of 30 ft (9.1 m);
- Precast concrete pier cap shells; and
- 24 in. (610 mm) octagonal precast, prestressed concrete piles.

All three alternatives had the potential, or had already demonstrated viability, for bridge application elsewhere in the United States. The three systems provided one or more of the following benefits over traditional CIP bridge construction: reduced traffic disruption; minimal adverse environmental impacts; low life-cycle costs; improved work zone safety; constructibility (rapid erection); and production quality.

The San Mateo-Hayward Bridge Widening Project was bid in October 1999, with the winning proposal entered at a bid price of $113 million. The successful bidder, Balfour Beatty Construction, Inc. (BBCI) of Suisun City, California, proposed executing Alternative 2, as described above. It is worth noting that, for a project of this magnitude, only about $20,000 separated the first and second place bidders and only $40,000 separated the first and third place bidders.

DESIGN CONSIDERATIONS

Seismic Requirements

The design of the structure focused on two difficult issues, the first being how to build the bridge immediately adjacent to the active Hayward Fault Zone (see sidebar). The second specification mandate called for a 125-year service life.

The seismic concerns had a major impact on the pile and girder designs.

THE HAYWARD FAULT

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The Hayward Fault is part of a network of north-south oriented strike-slip faults that criss-cross the San Francisco Bay Region in California as a result of pressure between the North American and Pacific Plates. The Hayward Fault is slowly creeping at a rate of about 5 mm (0.2 in.) per year resulting in deformations to a variety of structures in the densely populated East Bay.

The U.S. Geological Survey estimates that there is a 70 percent likelihood that the Hayward Fault (and other nearby faults) will cause a magnitude of 6.7 or greater earthquake to this region in the next 25 years. The Hayward Fault is less than 1.6 km (1 mile) east of the approach to the San Mateo-Hayward Bridge.

The geographical features of the East Bay are similar to those of Kobe, Japan, the site of the devastating 1995 earthquake. In both regions, a fault runs along foothills in a densely populated area overlooking a bay.

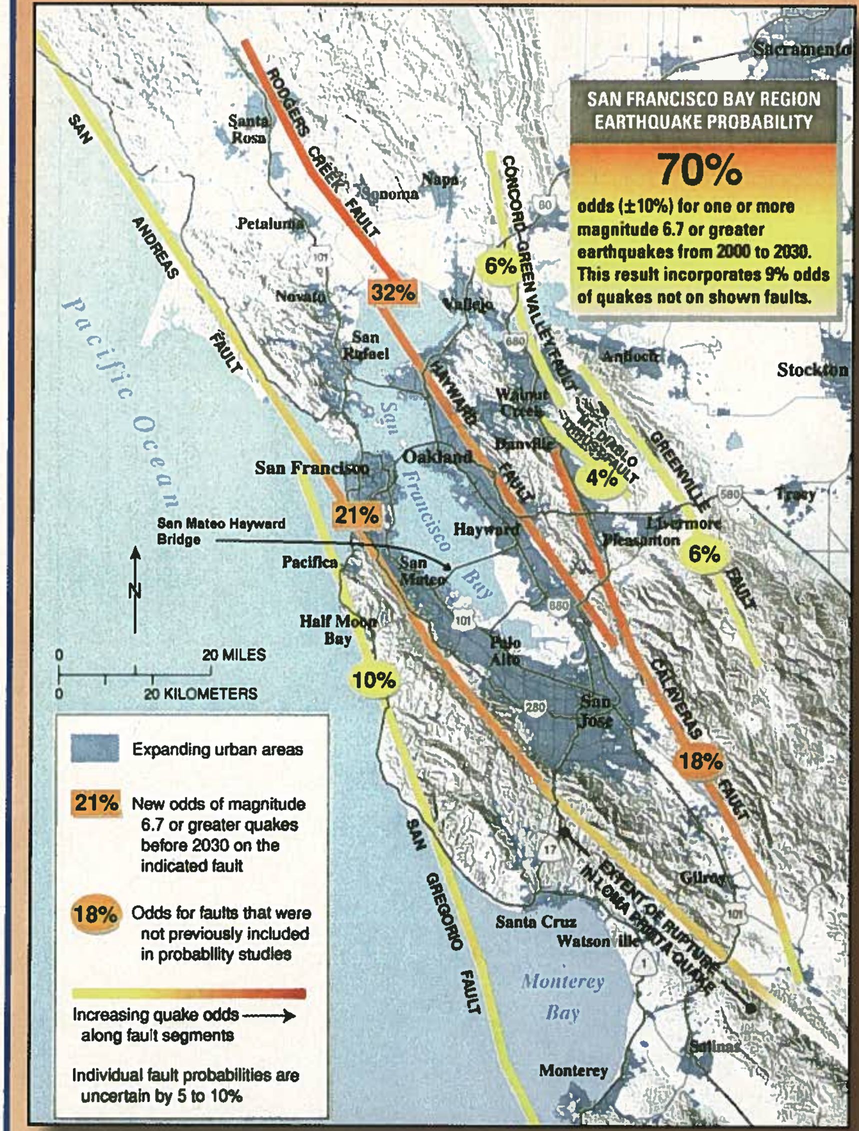

Fig. 7. Pile being removed from the form using slings and drop-out sections in the forms to eliminate the need for lift hooks. Lift hooks, even after removal and patching, could have presented potential ingress of saline water and subsequent pile reinforcing corrosion. (Courtesy of Pomeroy Corporation)

Providing the crucial support for the superstructure, the supporting piles must sustain significant lateral loads in the event of an earthquake. As a further serious complication to seismic loading, the San Francisco Bay mud—an unstable mix of sand, silty sand, and clay—offered little resistance to the oscillating waves of seismic forces, thereby significantly affecting the pile flexural lengths.

Typical lengths for the piles ranged from about 100 to 150 ft (30 to 45 m) with continuous full-length rebar that was mechanically coupled instead of lapped due to both seismic concerns and reinforcing steel congestion issues. In addition, all transverse reinforcing steel was designed as individual hoops that required fusion welding. All of

Fig. 8. Completed pile cage being lowered into the form at Pomeroy's precasting facilities in preparation for casting. Note the prestressing strand and the collapsible inner core form in place and lifted out as a single unit. (Courtesy of Pomeroy Corporation)

Fig. 9. Closeup of collapsible hydraulic core form. (Courtesy of Pomeroy Corporation)

Fig. 10. The crew installing the pile-driver follower over precisely positioned steel dowel bars extending from the top of a pile. The follower allows the energy from the pile driver hammer to be delivered to the top of the pile itself while simultaneously protecting the vertical pile reinforcement. Note the wooden pile driving cushion has already been installed. (Courtesy of Balfour Beatty Construction)

the remaining steel, including the prestressing strands, were epoxy coated. The most efficient method for producing the massive and complex pile reinforcing cages was to fabricate the cage outside the pile form and lower the 30 ton (27 Mg) cage assembly, complete with the hydraulically collapsible steel core void, into the form (see Figs. 7 to 10).

Precast concrete girder design was also affected by the seismic considerations of the site's geology, but to a lesser degree than that of the pile design. The potential for vertical acceleration during an earthquake required the designers to allow for a significant positive moment at the bent. The design called for reinforcing steel in the bottom of the girders to be extended and mechanically coupled. Since all steel reinforcing bars required epoxy coating, after installation in the field the rebar couplers were coated with a heat-shrink rubberized sleeve to provide corrosion protection (see Fig. 11).

One unique feature of the girder design was the interface between the precast concrete girders and stay-in-place deck panels. Girder camber necessitated placement of a small curb along the top outside edge of the flange. This concrete curb varied in depth to provide a level top surface on which to set the deck panels. A thin rubber bearing strip, about 1 to 1½ in. (25 to 40 mm) wide and ¼ to ¾ in. (6 to 20 mm) thick, was placed on top of the curb to provide a flexible seat and compensate for any minor surface deviations.

125-Year Service Life

To achieve the specified 125-year service life objective for the new bridge, CALTRANS designers introduced several additional design criteria. Since the bridge would be subjected to an aggressive calcium chloride-laden marine environment, several lines of corrosion defense were proposed. First, as previously mentioned, all reinforcing steel, mesh and prestressing strand used in the structure were required to be epoxy coated.

In addition, specifications called for coating of all the structural elements; this requirement would entail both exacting procedures and special attention in scheduling production for the project. Production lead times of one month were required in order to allow for fabrication, coating, and the specified laboratory testing of the coating mandated by the owner. Inventory control was critical to ensure a consistent supply of precast concrete materials for uninterrupted production needed to meet the project completion date.

Whenever precast concrete bridge systems are used in seismic regions, monolithic action between the precast components, especially between the superstructure and substructure, is considered key to achieving adequate structural ductility and resistance. During the design of the alternatives for the San Mateo-Hayward Widening Project, there were no pre-existing design methods established for the precast concrete system and connection details that would conform to the CALTRANS Seismic Design Criteria.

However, monolithic behavior was assumed in the design of the San Mateo-Hayward Bridge Widening because of the use of a major CIP pour. The superstructure was made continuous longitudinally and integral with the substructure by placing concrete at each bent cap location. Similarly, the superstructure elements were made integral to achieve monolithic action through the use of a concrete topping placed over the precast concrete stay-in-place deck panels.

Fig. 11. Portion of the pier cap reinforcing steel above the extended rebar of a pier, just prior to the installation of the cap reinforcing steel. Note the mechanically coupled reinforcement extending from the bottom portion of each girder for positive moment forces at the bent. (Courtesy of Balfour Beatty Construction)

Superstructure

Taken during construction, the photograph in Fig. 12 shows the superstructure composed of the eight 3.66 ft (1.1 m) deep modified pretensioned California bulb-tee girders that span an average length of 90 ft (27 m). Over the girders, precast, pretensioned concrete deck panels, about 8 x 5 ft (2.4 x 1.5 m) and 3⅛ in. (80 mm) thick, were installed. The deck panels eliminated time-consuming and costly CIP interior bay formwork and removal, and the 90 ft (27 m) long girders rapidly accelerated construction (see Fig. 13).

The concrete deck was poured directly on the precast stay-in-place deck panels, producing a 60 ft (18.2 m) wide composite deck. With a deck thickness of 7.5 in. (190 mm), the total superstructure deck depth including cap measured 4.5 ft (1.37 m). The superstructure depth-to-span length ratio is 0.05.

Fig. 12. End view of bridge widening construction reveals the eight bulb-tee girder layout beneath the precast deck slabs. (Courtesy of CALTRANS District 4 Photography Department)

Substructure

Partially precast U-shaped bent caps were designed to provide a ledge for the girders during erection and a means to construct an integral monolithic connection between the superstructure and substructure. The precast portion of the caps is 2.5 ft (0.75 m) deep. Once a precast cap was positioned over the precast pile and "locked" into the piles by field-placed reinforcing steel and the CIP closure placement, the superstructure construction began with the erection of the precast concrete girders supported by the precast cap.

Three 42 in. (1067 m) diameter precast, prestressed hollow concrete piles support each bent cap, and two piles support the cap at tie-in locations to the old bridge. Over 275 precast pile caps and 826 precast, prestressed concrete piles were used in the construction of the new substructure (see Table 1). Completed bent caps achieved an increased depth of 7 ft (2.1 m) after the large closure pour. As shown in Figs. 14 and 15, the coated steel reinforcement from piles extends through a prefabricated hole in the bottom of the bent cap to ensure a fixed connection between the pile and bent cap. Steel deck reinforcement was made continuous as well.

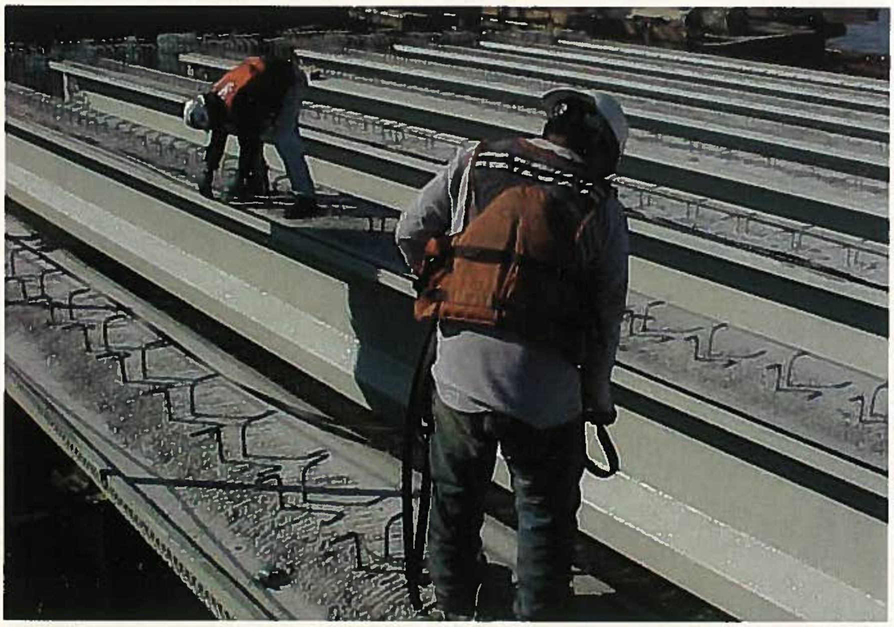

Fig. 13. Erection crew placing the rubber strip on top of the girder curb. This system supported the precast concrete flat slabs. (Courtesy of Balfour Beatty Construction)

Table 1. Precast concrete components and material inventory for the San Mateo-Hayward Bridge Widening Project.

Component	Quantity	Number
42 in. (1067 mm) diameter precast, prestressed concrete cylinder piles	96,846 lineal ft (29519 m)	826
Precast concrete bent cap shells	15,453 lineal ft (4710 m)	278
42 in. (1067 mm) precast, prestressed bulb-tee girders	187,084 lineal ft (50023 m)	2168
3.25 in. (83 mm) precast, prestressed concrete deck panels	893,530 sq ft (83009 m^2)	19,000
	TOTAL	22,272

Material	Quantity
Reinforcing steel and prestressing strand	6000 tons (5442 Mg)
Concrete (silica fume and fly ash)	60,487 cu yd (46248 m^3)
Epoxy strand (silica impregnated)	8.4 million ft (2.6 million m)
Epoxy rebar (A706)	12,800 tons (11600 Mg)
Epoxy mesh (A82)	421 tons (381 Mg)
Total quantity of polyurea coating (PolySpar HP)	11,430 gal. (43,265 L); coverage: 3.6 million sq ft (0.3 million m^2)

Expansion Joints

Expansion joints were placed at every third bent. At fixed bents, the superstructure was made continuous longitudinally by mechanically butt-splicing three No. 11 (36M) steel bars that protruded from the bottom flange of each girder. Mechanically spliced reinforcement provides adequate flexure capacity to resist the plastic hinging moment from the piles during a seismic event.

At each expansion joint bent, the three No. 11 (36M) girder bars were hooked into the bent cap to create a fixed connection to one span. The other side of the bent cap has an expansion joint seat on which the adjacent superstructure span rests. Steel pipes were used at each expansion joint to resist both longitudinal and transverse seismic loads. Adequate seating width and seismic load-resistant pipes prevent unseating of the girders.

PRODUCTION CHALLENGES

Material Control

Pomeroy Corporation of Petaluma, California, was the precaster for the project. Each week during construction, Pomeroy had to be prepared to deliver to the bridge site as many as 12 precast, prestressed concrete piles, 4 precast concrete pile caps, 32 precast girders, and 280 precast deck panels.

The precaster's preparation, organization, plant equipment, and production for the bridge widening project had to be superbly managed to meet the requisite volume of product. This project's daunting production rate attests to the inherent advantages of rapid erection and low unit cost afforded by precast concrete bridge systems.

Material inventory control was the paramount task for keeping the project on track, according to Pomeroy's project manager. Reinforcing steel production had to meet stringent specifications at the precasting plant. The following describes the reinforcement production sequence:

1. All reinforcing steel bar and prestressing strand were tested first, then epoxy coated. Afterwards, the coating itself was tested. Each production step could not proceed without the approval of the previous step.

2. Testing and approvals were conducted by the CALTRANS METS (Material Engineering and Testing Services) Laboratory.

3. For seismic purposes, the transverse reinforcing in the piles were constructed with individually fusion-welded hoops. Consistent with other production procedures, welding was inspected and approved in lot numbers before the corrosion-protection coating could be applied.

4. Pomeroy designated one full-time employee to track all materials throughout the entire production process and for the duration of the project. Exact numbers of materials in each phase of the process were identified and recorded to ensure adequate product to sustain the bridge erection schedule.

Polyurea Coating

As a further measure to extend the service life of the bridge beyond the 125-year design life, a polyurea coating was chosen to seal the surface of the concrete. Typical applications for this material was as a sealer for concrete warehouse floors; the San Mateo-Hayward Project was the first time this particular coating material was ever used on a bridge structure in California. Because of the extensive nature of the procedures and facilities required, the polyurea coating portion of the contract was sub-subcontracted under Pomeroy Corporation, and application took place at Pomeroy's precasting plant in Petaluma.

The contract required that the polyurea coating be applied to the complete underside of the superstructure. Plant application of the coating was a major operation that was set up on a 10 acre (4.1 ha) parcel at the precasting yard. Both the polyurea primer and finish courses were extremely susceptible to moisture and had a narrow range of temperatures over which to gain the required adhesion to the concrete.

To be certain the polyurea application was carried out properly, three buildings were constructed to ensure quality control and continuous all-weather coating operations. Because of the environmental concerns at the bridge site, the complete undersides of all precast bridge elements were coated under established quality control and testing procedures at the plant facilities.

Extensive painting operations were established under strict climate temperature and humidity control so that the polyurea material could be applied in accordance with the manufacturer's specifications. The polyurea operation entailed construction of nested telescoping buildings where the precast components were placed on supports and prepared for coating applications.

Two 1 acre (0.4 ha) telescoping buildings were used for coating of the larger precast concrete products. Straddle carriers placed the product on specially

Fig. 14. Pile-cap connection immediately prior to field installation of reinforcement and placement of CIP concrete to secure the cap to the pile. Note top of precast pile and vertical pile reinforcement extending through the opening of the precast cap. (Courtesy of Balfour Beatty Construction)

Fig. 15. A friction collar was used to temporarily support the precast caps. The collar remained in place until the precast cap was permanently attached to the piles with field-installed rebar and a CIP pour. (Courtesy of Balfour Beatty Construction)

Fig. 16. Climate-controlled building protects bridge piles during polyurea coating application at the Pomeroy plant. (Courtesy of Pomeroy Corporation)

Fig. 17. Piles are loaded into the coating area prior to rolling the nested building enclosure into place over the piles. (Courtesy of Pomeroy Corporation)

designed supports that allowed 360-degree access to the product for painting. The telescoping enclosures rolled over the precast components as the coating application progressed. The deck panels were coated in a 2 acre (0.8 ha) fixed building that was accessible by forklift. The stay-in-place deck panels were cast bottom side down, and were turned over using a special forklift attachment and set on elevated dunnage making it easier to apply the polyurea. After coating, the panels were turned back over to be stacked and loaded out.

The polyurea application process is summarized in the following steps (see Figs. 16 to 18):

1. Thirty days after precast concrete product casting, the polyurea coating was applied.

2. All concrete surfaces to receive a coating were roughened with a whip blast (sandblasting).

3. All bug holes in the concrete were patched with a filler material because the coating would not span over depressions in the surface.

4. The primer coat was applied and allowed to become tacky.

5. A finishing top coat of polyurea was applied to precast components.

6. CALTRANS METS Laboratory performed specified adhesion tests to ensure proper coating application and thickness.

Since only touch-up painting of the coating material to the precast concrete was permitted on the project site due to water quality and other environmental issues, all of the precast concrete pier caps, bulb-tee girders and deck panels were prepared and coated prior to the product leaving the precasting plant.

The substructure of the bridge, which would be in direct contact with the brackish bay water, required that the specified polyurea coating be applied to the top of the piles and extend 20 ft (6.1 m) below the point of low tide. CIP concrete required on-site coating, including the bridge overhangs and pier cap diaphragms; the CIP coating operation was performed by a subcontractor to Balfour Beatty.

A total of 3.6 million sq ft (0.3 million m^2) of polyurea was applied to the precast concrete components at a total cost of approximately $12 million. The process and procedure for the entire coating operation totaled approximately 10 percent of the total cost of the completed bridge (see Table 2). The contractor and precaster decided early in the planning stages that the least costly and most efficient method for the extensive polyurea coating operation would be to apply as much of the coating as possible away from the environmentally sensitive project site and in a controlled production environment.

Analysis of various options for the polyurea operation revealed that the cost of applying the polyurea to the bridge elements after erection—as would be the case with a CIP construction scenario—would have cost $20 to $30 million more than the project team's proposed solution. A precast facility coating operation was a significant savings to the owner, and a sound reason for selecting a precast concrete structure and the production environment afforded at a precasting plant.

Concrete Mixture Design and Curing

The corrosive marine environment raised a serious concern over the chloride permeability of the concrete surrounding the reinforcing steel in the precast concrete bridge components. To address this concern, a concrete mix design consisting of 20 percent fly ash and 5 percent silica fume was specified. Concrete with such a high percentage of pozzolans required special curing considerations to produce the desired low permeability values and avoid any inherent cracking.

The precaster experimented with and tested numerous concrete mix trial batches and curing processes until the specified concrete permeability was achieved. Concrete compressive strength at prestress transfer was typically 4000 psi (28 MPa) for the precast bent caps, piles, bulb tees, and deck panels. At about 35 days after casting, the concrete compressive strengths for the precast products ranged from 5000 to 6500 psi (35 to 45 MPa).

The San Mateo-Hayward Bridge Widening Project comprised 22,272 precast, prestressed concrete components (see Table 1).

CONSTRUCTION SEQUENCE

Work Platform

Because the shallow and ecologically fragile San Francisco Bay waters at the bridge site precluded the environmental disruption of typical marine construction equipment, the design and development of an efficient and mobile work platform became a major challenge for BBCI's project team (see Fig. 19). The temporary, moveable platform, or trestle, had to support all construction loads, including the weight of two heavy 250 ton (227 Mg) cranes and the hoisted precast concrete components, some of which weighed in excess of 43 tons (50 Mg). The largest precast, prestressed concrete pile was about 135 ft (41 m) long and weighed over 57 tons (52 Mg).

In addition, the 1080 ft (330 m) long trestle had to be safe to operate in the variable marine conditions (tide, wind, wave chop, current) and easy to advance at a rate of up to 360 ft (110 m) per week. BBCI designed 30 ft (9.1 m) long steel segments that could be quickly installed and moved in coordination with the scheduled bridge progression. The specified length of the trestle was designed to accommodate efficient progress in the erection of the pile caps and girders (see "Pile Cap and Girder Erection" below).

Fig. 18. Cylinder piles on custom-made steel supports that allow the polyurea coating to be applied to the full pile surface without having to turn or move the product. (Courtesy of Pomeroy Corporation)

Table 2. Bridge project data.

Award of contract	November 1999
Start of precast production	June 2000
Start of construction	December 1999
Bridge length	4.9 miles (7.9 km)
Bridge width	58.5 ft (17.8 m)
Deck area	1.5 million sq ft (141000 m^2)
Number of spans	278
Typical span length	93.0 ft (28.3 m)
Substructure cost	\$23.00/sq ft (\$248/m^2)
Superstructure cost	\$50.00/sq ft (\$538/m^2)
Polyurea coating cost	\$12 million
Precast concrete total cost	\$45 million
Total project cost	\$138 million
Production rate	270 ft (82.3 m) per week
Project completion	October 2002

Barge Transport

The primary concern for both CALTRANS and the affected local communities of Hayward and San Mateo was how to build a bridge of this magnitude without adding to the existing congestion. With over 22,000 precast concrete components in the project, material transport other than the

Fig. 19. Work platform supports crawler-mounted erection crane with counterweights. (Courtesy of Balfour Beatty Construction)

Fig. 20. Hoisting of precast deck panels with panel placing machine during construction. Ten precast concrete deck panels were used in each span. (Courtesy of Balfour Beatty Construction)

usual land-based truck delivery would have to be considered.

Water-borne transport was the only feasible product delivery option. Barges were loaded at the dock of the Pomeroy plant boat slip on the Petaluma River, and shipped about 60 miles (100 km) south to the bridge site. A straddle carrier was used to load the precast elements on to the barges at the Pomeroy facility. Barge travel time from the precast docking facility to the temporary moorings near the bridge site ranged from 8 to 10 hours one way, at speeds that varied from 5 to 10 miles per hour (8 to 16 km/hr) depending on marine conditions.

Barge delivery of precast concrete components had the critical advantage of eliminating adverse impact on the already congested local freeways. The barges were loaded in such a way that all of the precast components to be erected in a given week were delivered on two 600 ton (544 Mg) barges. There were a total of six barges in the project fleet. The barges were dispatched in pairs, with weekly barge deliveries transporting sufficient precast concrete building materials to construct two 90 ft (27.4 m) long bridge spans.

The San Mateo-Hayward Bridge Widening Project typically required two barge deliveries each week to maintain the scheduled construction progress on the bridge. This transportation plan allowed the bridge widening work to proceed with completion of three spans, or 270 ft (82.3 m), per week (see Figs. 20 and 21).

Pile Driving

As the precast, prestressed concrete piers were shipped to the site, the components were offloaded and fitted with the pile follower (see Fig. 10) and driven segment by segment into the bay mud. Because the contractor planned on using a very large hammer for driving the piles to tip elevation, there was some concern that the impact force of the driving hammer might overstress the piles as they were driven through the soft bay mud.

To alleviate this concern, a consulting engineering firm contracted by BBCI, Ben C. Gerwick of San Francisco, California, conducted a preliminary drivability test to evaluate the tension stresses generated by the contractor's pile-driving equipment on the effective prestressing of the concrete pile design. Through early evaluation and teamwork, the project team was able to quickly identify and remedy a situation that had the potential for significant and costly delays. As a result of early collaboration and the drivability test confirmation, additional prestressing strands were incorporated in the pile design to prevent damage to the piers during pile-driving operations (see Fig. 22). More than 800 precast concrete piles were driven over the course of 700 working days.

Pile Cap and Girder Erection

Once the pile for an individual pier was driven to grade, the partially precast U-shaped bent caps with corresponding openings for pile placement were installed over the piles, and the column-to-cap connection was completed by filling the bent cap shell with CIP concrete. Pile caps for bridges are typically built with CIP concrete due to the high density of the reinforcing steel required within a limited volume of concrete. Precast concrete pile caps for the San Mateo-Hayward Bridge Widening Project were unusual and innovative in that the precaster was able to overcome the inherent difficulties of fabricating rebar-congested components by successfully mass producing the caps in a precast facility assembly process.

Once the precast concrete pile cap was erected in the field, reinforcing steel was installed in the "U" portion of the precast cap. After the pile-to-cap joint reinforcing steel was in place, CIP concrete was placed in the U-portion of the cap and in the upper 20 ft (6.1 m) of each pile. This single CIP pour effectively locked the precast cap to the precast pile, creating a monolithic structure.

The girders were erected on the caps once the CIP cap-to-pile connection concrete had achieved sufficient strength. It is interesting to note that the reasoning behind the 1080 ft (330 m) design length of the work trestle was to accommodate completion of the pile caps—allowing sufficient time for concrete cure—while facilitating efficient erection of the girders as the work advanced.

Precast, pretensioned bulb-tee girders were erected and braced, and precast concrete stay-in-place deck panels were then placed on top of the girders. After deck reinforcement was installed, a 5 in. (127 mm) topping slab was poured. Construction of the entire bridge widening project was scheduled to take three years and was actually completed ahead of schedule.

PRECAST CONCRETE ADVANTAGES

Fig. 21. At the precast plant boat slip, one of the loaded barges prepares for its 60 mile (100 km) southbound trip down the Petaluma River to the San Francisco Bay and the bridge site. (Courtesy of CALTRANS District 4 Photography Department)

The extensive use of precast concrete components on this project provided CALTRANS with many advantages over the alternative bridge systems:

1. Elimination of falsework over the shallow, environmentally sensitive San Francisco Bay.

2. Rapid and economical construction afforded by the precast, prestressed concrete superstructure and substructure system.

3. Elimination of superstructure (bridge roadway traffic) congestion through water-borne delivery of all precast concrete components. Relegating precast concrete delivery to barge-based operations and the use of a moveable work trestle produced the critical advantages of both minimizing traffic disruption and improving work zone safety.

4. Tested and approved plant-produced precast concrete components ensured product quality and durability.

5. Design of a partially precast bent cap allowed construction process advantages through: the provision of a ledge for a convenient means to support the girders for rapid erection; reduction of reinforcement congestion issues (time and labor costs) typically encountered in bent cap construction through prefabricated cap assembly; and creation of an effective connection method to ensure monolithic structural behavior and connection continuity for seismic performance.

6. Overall, the use of precast concrete components and the innovative design of connection details and components allowed the project to be completed ahead of schedule and at a low total construction cost.

RESEARCH RECOMMENDATIONS AND CONCLUSIONS

Superstructure

A full-depth precast, pretensioned concrete deck system should be compared with existing U.S. technology and research efforts, and further developed in California to validate and enhance connection details for implementation. The U-shaped precast segment with a horizontal rib should be further studied and considered for implementation on precast segmental bridges, especially where site restrictions or location limit on-site segmental production.

Precast concrete continuity details from Japan and Europe should be examined through research and considered for implementation in California. Differences in construction quality, factors of safety, and tolerances between other countries and the United States should be considered in further developing these details. When structural continuity is properly incorporated into the design, the spliced precast concrete girder

Fig. 22. Piles were located by GPS and template. After spotting, the pile was released and wound run 40 ft (12 m) into the bay mud under its own weight. The driving hammer was then used to drive the pile to elevation. (Courtesy of Balfour Beatty Construction)

system provides a highly advantageous solution for bridge construction in seismic regions.

Substructure

Partially precast systems for bent caps and piers offer wide-ranging benefits for bridge construction in seismic regions and should be considered for implementation in California. However, the design basis and connection details need to be further developed. Research should be funded to develop a design methodology, establish connection details, and produce specifications for a range of precast bent cap-to-column connections.

Use of innovative precast, prestressed concrete bridge systems for seismic regions in California is increasing. According to the FHWA/AASHTO report,[1] precast, prestressed bridge applications in Japan and California have been very successful. Precast concrete systems have provided one or more of the following benefits over traditional CIP construction: reduced traffic disruption and minimal adverse effects on the environment (elimination of falsework), reduced life-cycle cost, improved work zone safety, rapid erection, and production quality. California's experience on the San Mateo-Hayward Bridge Widening Project has demonstrated the advantages and applicability of precast, prestressed concrete for bridges in high seismic regions.

The use of precast, prestressed concrete at the San Mateo-Hayward Bridge allowed CALTRANS to meet the broad design criteria and the stringent environmental criteria identified in the preliminary feasibility studies. Clearly, the fact that the three bid alternatives proffered consisted only of precast concrete bridge structures was a confirmation of precast concrete systems as the "solution of choice." This project marked a significant milestone for the advancement of the precast, prestressed concrete industry in a state that, until recently, primarily built bridges using CIP concrete construction.

Moreover, the San Mateo-Hayward Bridge Project was completed on budget and ahead of schedule, opening in October 2002, three years after the contract award (see Fig. 23). The twinning completed the final phase of the overall comprehensive bridge upgrade which began five years earlier with a major seismic retrofit to the higher elevation portion at the east end, or Hayward side, of the crossing.

Not only did the project meet the owners design criteria and expectations, but it also became the focal point for the local community and media. As the project moved across the bay at a consistent rate of nearly 300 ft (90 m) per week, local groups and the favorable media coverage charted the bridge progress as it moved closer to completion. Even with intense public scrutiny, the project was completed without any violation of local or federal environmental laws. In fact, there were no NOVs (Notice of Violation) issued by the EPA for the duration of construction—a remarkable accomplishment for a project of this magnitude. The bridge erection was completed in just 110 weeks.

PCI JUDGES' AWARD COMMENTS

The San Mateo-Hayward Bridge Widening Project was selected by PCI in 2004 as co-winner in the category Best All-Precast Solution. The jury commented: "This project is unique in that a total precast concrete structure proved to be structurally superior and economical to other options for this type of solution. The seismic design details incorporated into the structure also were accomplished well. Using epoxy-coated reinforcing steel, high performance concrete with silica fume, and other special details will help ensure the structure achieves its 125-year design life."

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Fig. 23. Aerial view of the bridge widening under construction. (Courtesy of CALTRANS District 4 Photography Department)

CREDITS

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Consulting Engineer: Ben C. Gerwick, Inc., San Francisco, California

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