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Additional Bridge Products

16.1 INTRODUCTION

Precast concrete products that are manufactured for bridges are not limited to superstructure members such as I-beams, box beams and voided slabs. Many additional precast components are widely used. These products have been used successfully, some for more than 50 years, and have been proven economical. The advantages cited for precast beams are characteristic of a large number of other bridge components. Speed of construction and the consistent high quality of precast products are equally valuable to the owner and contractor for these other parts of the bridge. Some of these precast components for bridges include stay-in-place (SIP) deck panels, full-depth deck panels, piles, pile bent caps, railings, piers, pier columns and abutments. Precast systems are also used for earth retaining systems and box culverts. Each of these applications of precast products is discussed in this chapter.

16.2 STAY-IN-PLACE DECK PANELS

Precast, stay-in-place (SIP) deck panels are precisely-designed and fabricated precast concrete slabs spanning between concrete or steel beams. They serve as a form for the cast-in-place (CIP) deck concrete and provide the principal positive moment reinforcement in the composite deck. That is, the prestressing or conventional reinforcement in the panel is designed to resist the self-weight of the panel and the weight of the field-placed concrete topping as a non-composite section. Then, after the field-placed concrete topping cures, the SIP panel becomes an integral part of the composite deck that resists all subsequent dead and live loads applied to the deck. See Section 3.8 for more information on the fabrication of SIP panels.

16.2.1 Advantages

SIP panels provide a permanent structural form for the bridge deck. The contractor is able to quickly use a broader and therefore safer working area provided by the panels. In addition, there is no need for the contractor to remove formwork after the CIP portion of the deck has cured, thereby saving a considerable amount of labor, time and exposure. The contractor saves the time, labor and material of having to install a bottom mat of reinforcing steel. The amount of field-placed and field-cured concrete is substantially reduced compared to a concrete deck cast on removable or steel forms. **Figure 16.2.1-1** illustrates the working surface provided by the installation of SIP panels on the Louetta Road Bridge (Ralls, et al, 1993).

Figure 16.2.1-1
SIP Panel Erection between Precast Concete U-Beams

SIP panels are fabricated using dense, high performance concrete that resists chloride intrusion. The prestressed panel is designed to be crack-free throughout its depth for all loading conditions. Research and practice have shown that panels placed with tight joints result in excellent local continuity even without dowels projecting across joints. Although some cracks have appeared in the CIP portion of the deck, these cracks are generally smaller and of less consequence than cracks in fully-cast-in-place decks. Research by Tsui, et al, 1986, has shown that decks properly constructed with precast, prestressed SIP panels are stronger, stiffer and more crack-resistant than CIP decks.

16.2.2 Size Selection

The depth of SIP panels that are commonly used for composite decks, ranges from 3 in. to 4.5 in., based largely on the design span of the deck. The depth of the SIP panel should be as deep as necessary to provide the maximum benefits from the use of precast concrete while allowing for a depth of CIP concrete adequate to provide cover over the top mat of mild reinforcing steel.

The width of SIP panels (perpendicular to the panel span) is typically standardized on an even dimension of 4 or 8 ft. Narrower panels can be cast or cut to fill the spaces remaining at the ends of the bridge span. Panels cast or cut to skews may also be used at the ends of each bridge span.

SIP panel span lengths vary based on beam spacing and are feasible whenever a CIP deck may be used. Panel lengths can be as short as needed. Panels shorter than two times the development length of the prestressing strands must be designed to account for a reduced ultimate moment capacity or be provided with additional mild steel reinforcement. Sometimes only conventional reinforcement is used. The details should accommodate a minimum of 3 in. lap over each beam.

Panel thickness is important when choosing the diameter of the prestressing strands to be used. As illustrated in **Table 16.2.2-1**, the recommended ratio of panel thickness to strand diameter is 8:1.

Table 16.2.2-1 Recommended Strand Diameter for Panel Thickness Shown

Panel Thickness	Recommended Strand Diameter
3"	3/8"
3 1/2"	3/8" or 7/16"
4" or more	1/2"

16.2.3 Design Criteria

Stress limits for prestressed members are shown in the *AASHTO Specifications* (STD Art. 9.15.2; LRFD Art. 5.9.4.2). Tension limits depend on the environmental conditions at the project site. Typically, tension is limited to $6\sqrt{f_c'}$ for non-corrosive locations and $3\sqrt{f_c'}$ for corrosive environments. The stress history for both tension and compression must be determined for the SIP panel for non-composite and composite loads. As with other prestressed concrete design procedures, the design is based on the service condition (allowable stress) and then evaluated for ultimate capacity or strength. Design live load plus impact is identical to that used for a CIP deck. Considerable additional information on design is found in Section 8.8 and Design Examples 9.7 and 9.8.

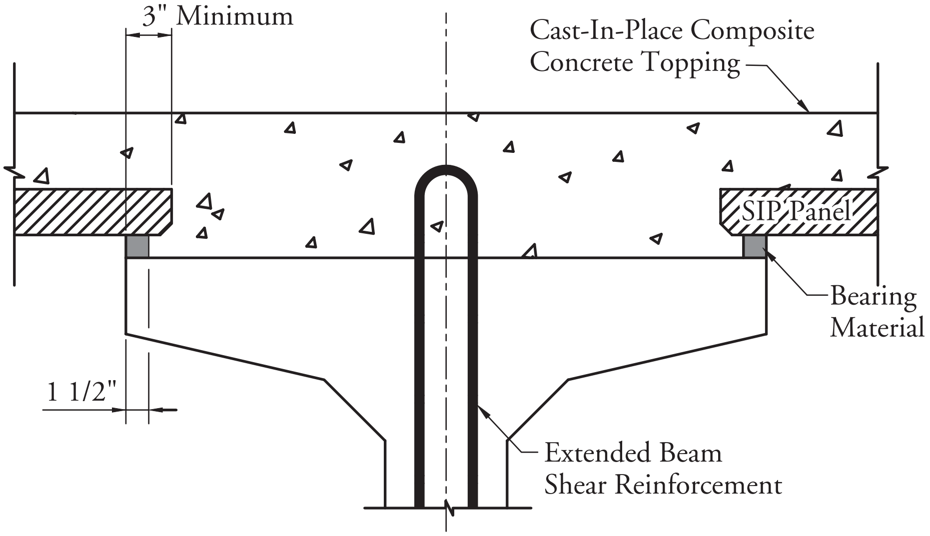
16.2.4 Design, Fabrication and Construction

The successful and economical use of SIP deck panels depends entirely on the selection of proper design, fabrication and construction details. These details include bearing on the girder, strand placement, strand extension, horizontal shear, provisions for handling and shipping, and even the age of the panels at installation. A discussion of each of these topics follows.

16.2.4.1 Bearing Details

The SIP panel must have positive bearing on the supporting beams. Typically, the panel is temporarily supported on a strip of slightly compressible material near the edge of the beam. The panel should overhang this bearing material by a minimum of 1.5 in. The bearing material must be tall enough to allow the CIP deck concrete to flow under the panel and completely fill the space between the top of the beam and the bottom of the SIP panel. Care must be used to ensure proper consolidation of concrete into this space. When the CIP concrete cures, it provides positive bearing for the panel and allows for transfer of superimposed loads from the deck to the beam **Figure 16.2.4.1-1**. Some panel systems use adjustable screw jacks to set the elevation of the panel and temporarily support the panel on the beam. Fillers are used between the panel and the girder. When the concrete cures, the screw jacks are removed and a solid, positive and permanent bearing remains. One system is shown in Chapter 3, Fig. 3.8.3-1. Some projects such as Fancher Road Bridge, 1984, have used side forms mounted on the beams to support panels together with non-shrink grout beneath panels. This method has proven less effective than others described.

Figure 16.2.4.1-1
SIP Panel Bearing Detail



16.2.4.2 Reinforcement

Proper strand placement during fabrication is very important particularly in a thin section like a SIP panel. The strands may be designed to be eccentric about the horizontal center of gravity of the panel. However, most designers place the strands concentric at mid-depth of the panel. Eccentricity increases the efficiency of the prestress force. It provides initial camber prior to placement of the CIP concrete. As always, specified concrete cover over the prestress strands must be maintained.

Welded wire reinforcement or reinforcing bars are provided as nominal shrinkage and temperature reinforcement to control potential cracking. Small-diameter bars are often used at the ends, both above and below strands, to control potential cracks due to transfer of force upon detensioning.

16.2.4.3 Strand Extensions

Research performed at the University of Texas at Austin (Bieschke and Klingner, 1982) indicates that there is no local or global difference in the performance of decks constructed using SIP panels with or without strand extensions. There is a significant implication to strand extensions. Strand extensions require the fabricator to install forms in the bed between each panel thereby increasing fabrication cost. If there is no strand extension, the panels may be cast in a single, long slab and subsequently cut to length when the concrete reaches transfer strength.

Strand extensions are generally not recommended. However, some designers prefer to use them citing these benefits:

- The use of a form between each panel in the prestressing bed helps assure proper strand position
- The extension acts as a dowel in the CIP deck
- The embedment of the strand into the CIP concrete may reduce the potential separation of the panel end from the CIP concrete that may be caused by creep, shrinkage and thermal effects.

16.2.4.4 Composite Behavior

Mechanical shear connectors are not required to achieve composite action between the SIP panel and the CIP slab. Full composite action is achieved if the deck panel is intentionally roughened during fabrication and is free of contaminants. Research by Kumar and Ramirez (1996) has shown that prestressed SIP deck panels with a 0.05 to 0.075-in. amplitude broom-finished surface do not require horizontal shear connectors to achieve full composite action with the CIP topping.

Thorough wetting of the SIP panel without ponding prior to placement of the CIP slab will provide adequate bond at the interface. Tests conducted by the University of Texas at Austin for the Texas Department of Transportation confirm excellent structural performance (Burns, et al, 1990-A and 1990-B).

16.2.4.5 Handling

Generally, the larger the deck panel, the more susceptible it is to damage during shipping and handling. Handling stresses should be investigated during design. Plans should provide details and locations for lifting and storing the panels. Storing and stacking should be done in a manner that does not induce undesirable stresses in the panels. See Section 3.3.8.3. **Figure 16.2.4.5-1** shows panels being delivered to a project site. If panels are handled in stacks, special support slings or lift devices may be required to prevent bending or torsion in the panels and overloading of panels near the bottom of the stack.

Figure 16.2.4.5-1 SIP Deck Panels being Delivered to Bridge Site

16.2.4.6 Age at Installation

SIP panels often contain relatively high levels of prestress. Therefore, creep can be an important consideration. It is desirable that panels be from one- to two-months old when the CIP portion of the deck is placed. This substantially reduces the potential for distress in the CIP deck associated with creep and shrinkage of the panel. Klingner (1989) makes the conservative recommendation that planks be at least two months old. He notes that satisfactory results have been achieved with less time. He provides procedures for calculation of more precise minimum time estimates.

16.2.5 Applications

Precast, prestressed concrete SIP deck panels are used extensively in several parts of the country. In most of these areas, state highway agencies have prepared standard designs and details that are incorporated in the plans for most bridges. Many major projects, as well as hundreds of smaller bridges have used SIP panels since the mid-1950s. When offered on plans as an alternate, experienced general contractors usually select SIP panels because of their inherent cost savings due to speed, safety and simplicity. These benefits are apparent in **Figure 16.2.5-1** where SIP panels were used to both cover and span between open-topped trapezoidal box beams.

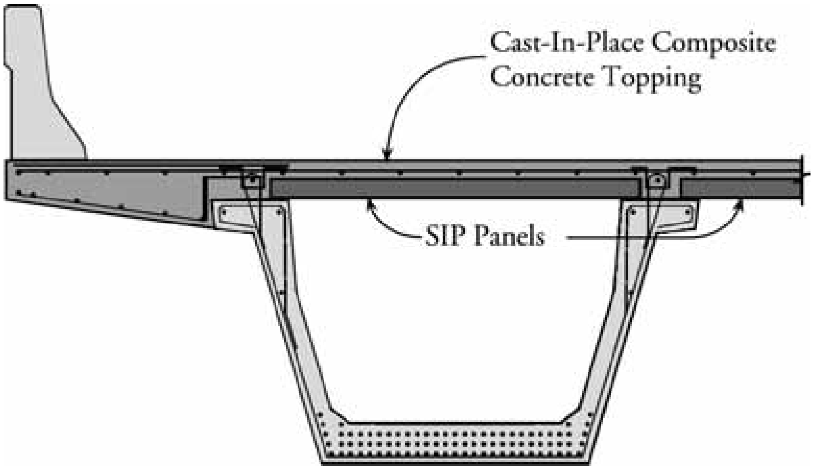


Figure 16.2.5-1
SIP Panels used with U-Beams
(Texas DOT)

16.2.6 Additional Information

The March/April 1988 issue of the PCI JOURNAL contains a Recommended Practice for Precast Concrete Composite Bridge Deck Panels. This report presents detailed recommendations for the design, manufacture and erection of SIP panels. The report also includes a thorough design example in accordance with the *AASHTO Standard Specification* in effect at that time.

Section 8.8 provides additional detailed design information. Design Examples 9.7 and 9.8 provide both *Standard* and *LRFD Specifications* examples, respectively, of deck panel design.

A unique precast composite deck system, NUDEK, is described in Section 8.8.3.1 and in Badie, et al, 1998. It provides a method to span multiple beams and eliminate the conventional forming of overhangs. The system is estimated to reduce construction time by 60 percent.

The following are references where additional detailed information on panel research and installations may be found: Buth, et al, 1972; Barker, 1975; Kluge and Sawyer, 1975; Texas Highway Department, 1975; Barnoff, et al, 1977; PCI Bridge Committee, 1978; Kelly, 1979; Kao and Ballinger, 1982; Slavis, 1983; and PCI Committee on Bridges, 1987.

16.3 FULL-DEPTH DECK PANELS

In addition to using precast concrete panels as stay-in-place forms for bridge decks, more and more projects are using precast concrete to provide the full depth of the bridge deck (Biswas, 1986). This product is particularly useful on projects where:

- The installation and stripping of forms proves difficult;
- The placement of large quantities of CIP concrete is difficult;
- Disruption of traffic is an overriding concern due to safety or user costs.

In these situations, the deck slab may be fully precast and then erected on the supporting members.

16.3.1 Applications

Full-depth deck panels are suited for bridge rehabilitation projects requiring new decks and especially in areas with high traffic volumes. The speed of installation is extremely important under these conditions. Culmo (1991) reports that in Connecticut, a six-span, 700-ft-long, one-lane ramp with compound curvature on a seven-percent grade was completely replaced in 48 days. On another project, 34 spans were replaced over two construction seasons using only 60-hour weekend closures. Entire spans were replaced within a 60-hour window (Culmo, 2000). The Pimmit Run Bridge on the George Washington Memorial Parkway in Fairfield, VA, has a length of 345 ft and a width of 68 ft. It was redecked inside of six weekend closures (Miller, et al, 1991).

Large sections of deck can be removed and replaced quickly, minimizing the impact to traffic. In many projects, traffic on a bridge has been maintained without significant interruption during construction. This was the case in the redecking of the Woodrow Wilson Memorial Bridge in Washington, DC (Lutz and Scalia, 1984).

Full-depth panels benefit new construction as well. In addition to speed of installation, all of the other unique advantages of precast concrete come into play, such as dense, durable concrete, reduced reliance on ready-mixed concrete and field labor, elimination of field curing systems and time-consuming field forming. Full-depth deck panel systems have proven cost competitive when compared to alternate construction methods. Enthusiasm over a redecking project in 1982 led to a proposed new deck system for bridges. It included a cost estimate that showed a system savings of more than eight percent (Kempf, 1983).

The report of a survey on full-depth panels conducted by Issa, et al (1995) revealed experiences and methods used by 13 states and one providence. The survey indicated that 43 states were interested in using this system of construction.

The growing interest by the owner agencies in methods to speed construction have resulted in the development of new full-depth deck panel systems. One unique panel system is described briefly in Section 8.8.3.2. It resulted from a federally-funded study by the Center for Infrastructure Research at the University of Nebraska (Tadros and Baishya, 1998). Even though it is a full-deck system, it is reported to be thinner and lighter then other concrete deck systems available. The panels use high performance concrete and are prestressed in both directions. A portion of this study with a description of load tests is reported in Yamane, et al (1998).

16.3.2
Reinforcement

Bridge decks have been successfully installed using panels incorporating either mild steel reinforcement or prestressing. Prestressed concrete panels may be pretensioned in the plant or post-tensioned in the plant or in the field. In most installations, some amount of field-applied post-tensioning has been used. The need for prestressing is dependent on specific project objectives and panel handling stresses.

16.3.3
Connections

Proper connection of full-depth deck panels to the supporting superstructure and to adjacent panels is important to ensure satisfactory performance of the deck. Various means have been used to connect full-depth panels to beams and panels to panels.

16.3.3.1
Panel-to-Beam Connections

Early installations of full-depth precast concrete deck panels used connections to beams that did not provide composite action. These simple connections, such as used at the Pintala Creek Bridge in Montgomery, AL, (Biswas, 1986) clamped the panels to the beams with a bolt and plate system. This ensured only that the panels would not be dislodged from the beams during subsequent construction operations (**Figure 16.3.3.1-1**). More recently, connections have been designed to transfer horizontal shear between the beams and slabs to make use of the efficiency of composite action. In most cases, a pocket is cast in the precast slab during fabrication. In some

Figure 16.3.3.1-1
Slab-to-Beam Connection, Pintala Creek Bridge

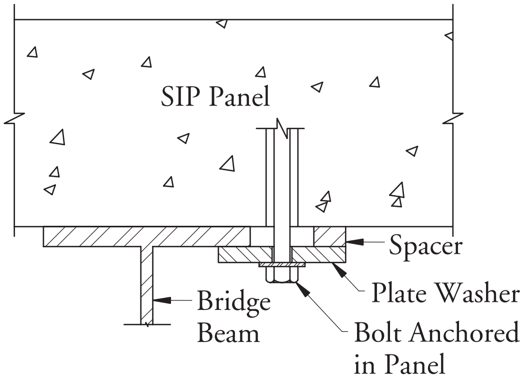
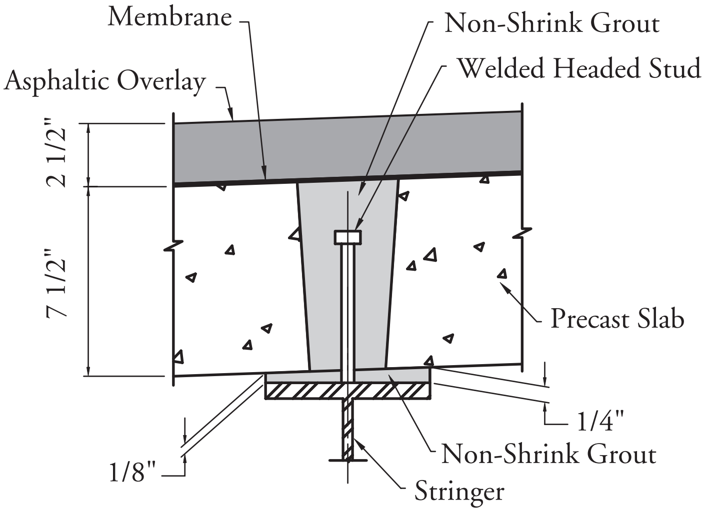


Figure 16.3.3.1-2
Slab-to-Beam Connection, Bridge No. 6, NYSDOT



instances, the locations of these pockets are coordinated with those of shear connectors attached to the beams (**Figure 16.3.3.1-2**). In most cases, shear connectors are attached to beams through pockets in the panels following erection of the panels. This eliminates problems with coordinating the locations of pockets and connectors. There is, of course, a slight increase in field labor. There were a few bridge decks built by the New York State Thruway Authority that had panels bolted directly to steel girders. Difficulty was reported in achieving proper bolt tension. In addition, slab-cracking caused by deflection due to bolt tensioning resulted in alternate methods of connecting decks to beams in subsequent installations (Biswas, 1986).

16.3.3.2 Panel-to-Panel Connections

Several panel-to-panel connection techniques have been developed in response to specific project requirements. Open gaps between panels have been provided that are sufficiently large to provide for lapped reinforcing bars that project from panel edges. These joints are then filled with field-placed concrete. This type of joint diminishes a primary advantage of speed of construction by requiring installation of forms and the placement and curing of concrete. Most installations have used keyways that are filled with non-shrink grout or epoxy mortar (**Figure 16.3.3.2-1**). In several projects, post-tensioning perpendicular to the panel joints was used to enhance performance of the keyway (Biswas, 1986). A significant analytical study was conducted by Issa, et al, 1998, that evaluates the performance of joints with different levels of post-tensioning.

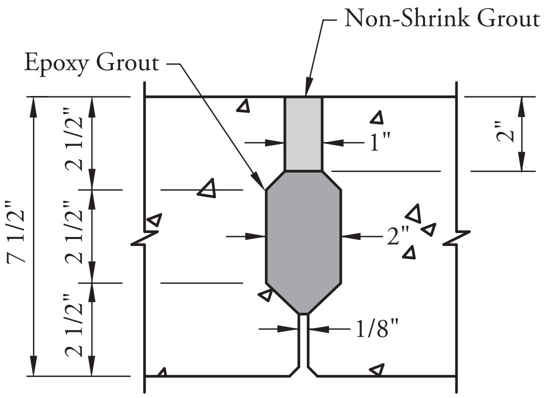


Figure 16.3.3.2-1 Panel-to-Panel Connection, Bridge No. 6, NYSDOT (Biswas, 1986)

16.4 PILES

One of the most versatile precast concrete components is prestressed concrete piling. Piles are not only used in bridge construction, but also in buildings and marine facilities. Prestressed piles have been in constant use since the inception of prestressed concrete. Thousands of installations throughout the country date back to the early-to-mid-nineteen fifties. Prestressed piles have generally demonstrated outstanding performance. Chapter 20 is devoted to an in-depth discussion of prestressed concrete piling applications including design, fabrication and installation.

16.4.1 Applications

The uses of prestressed concrete piling range from pier foundations for minor grade crossings to the foundations of major bridges over navigable waterways, such as the Sunshine Skyway Bridge in Tampa Bay, FL (Chandra and Szecsei, 1988). Concrete piles are especially effective for supporting bent caps. In this application, they extend from the ground into a cap that supports the superstructure. Two examples appeared in the PCI JOURNAL in 1989. These are the Bohemia River Bridge and the Richmond, Fredericksburg and Potomac Railroad Bridge.

Prestressed piles are used extensively to support abutments. Moreover, where soil conditions will not adequately support the spread footing of a retaining wall, piles have been successfully used to withstand both axial and horizontal loads from the soil. Prestressed concrete piles are also used as soldier piles for other earth retaining systems. Due to their ductility and large moment capacity, prestressed concrete piles are used as fender piles and to support piers that must be designed for large ship impact forces.

16.4.2 Pile Shapes

Prestressed piles normally are one of three cross-sections: square, octagonal or cylindrical. Square piles as small as 12 in. by 12 in. are commonly used in some states for bridge construction. Pile sizes generally increase in 2-in. increments from 10 in. to 20 in. and starting at 24 in., in 6-in. increments to 30 in. and 36 in. In some states, the three larger sizes are cast with a circular void through the cross-section. This reduces the volume of concrete, lowers cost, shipping and handling weights, and facilitates field handling. Using a voided section also reduces the required prestress force. Octagonal piles typically range in width from 10 in. to 24 in., measured from flat-to-flat, in 2-in. increments. The three largest sizes (20, 22 and 24 in.) may be solid or cast with a central circular void.

Round piles are usually made with a circular void and are referred to as cylinder piles. These piles are generally larger than square or octagonal piles. Typical outside dimensions for cylinder piles are 36 in., 42 in., 54 in. and 66 in. The wall thickness is usually

5 in. but may be as much as 8 in. Cylinder piles are very effective when large vertical and/or horizontal forces are expected, such as for crossings over navigable waterways.

Square and octagonal piles are usually cast in long-line forms. Cylinder piles are usually fabricated in shorter sections and then post-tensioned together in the casting plant to provide the required length of pile. They may also be cast as one piece in long-line forms. Cylinder pile sections can be spun cast (compacted centrifugally) using closed forms. This increases the density of the concrete, reduces the water/cementitious materials ratio and even further improves the quality of these precast, prestressed concrete products.

16.4.3 Advantages

Prestressed concrete piles provide a very economical method of constructing deep foundations. Readily available local materials are used in the concrete mixture. Being prestressed, the pile can easily be handled, shipped to the project and driven to the required capacity. **Figure 16.4.3-1**, taken from Table 2.7.1 in the *PCI Design Handbook*, provides guidance for the designer concerning allowable concentric loads on prestressed piles. These values must be evaluated based on soil conditions and the ability of the soil to support loads.

Prestressed concrete piles exhibit substantial corrosion resistance. There is no steel exposed to the elements. The concrete is uncracked, dense and of high quality, typical of the concrete associated with plant-cast products. In some areas, engineered concrete mixtures are used to enhance the durability of the piles.

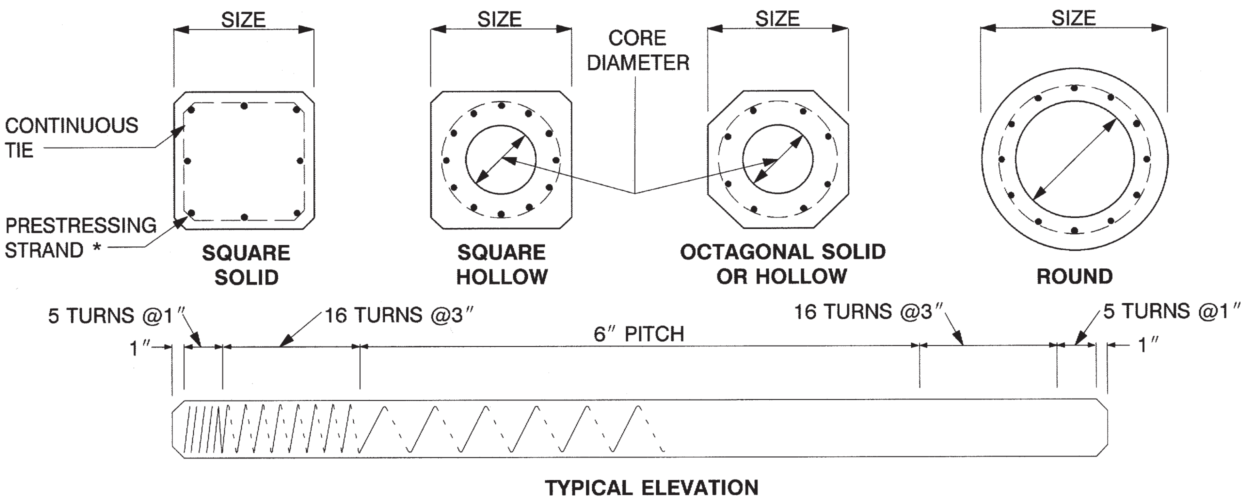
For most applications, the ability of the pile to transfer loads to soil is based on a combination of skin friction and end bearing. The shapes of prestressed concrete piles provide both a large surface area for friction, and a larger bearing area than most other pile shapes. This likely will reduce the length of pile necessary to obtain specified capacities.

16.4.4 Installation

The successful installation of prestressed concrete piles begins with proper handling and transportation. Damage to the piles may occur if not lifted, stored and transported according to proper industry practices. Once properly placed in the driving leads, a cushion, usually made from layers of plywood, is placed on the top of the pile to protect it from hammer damage during driving. The size of the hammer, the energy imparted during driving and the thickness of the cushioning material are all important considerations. A Wave Equation Analysis of Piles (WEAP) is often used to model the hammer-pile-soil interaction and to identify potential installation problems. These problems may include overstressing due to the use of an oversized hammer or the pile may reach premature refusal above the required pile tip elevation due to the use of an undersized hammer. Use of WEAP can supplement dynamic formulas in estimating the ultimate capacity of the piles and the required blow count to achieve that capacity. **Figure 16.4.4-1** shows the installation of cylinder piles. Note the joints where the pile segments have been grouted and post-tensioned together during production.

Figure 16.4.4-1
Driving Cylinder Piles

Figure 16.4.3-1 Section Properties and Allowable Service Loads of Prestressed Concrete Piles



* Strand pattern may be circular or square.

SIZE (in.)	CORE DIA. (in.)	SECTION PROPERTIES [a]						ALLOWABLE CONCENTRIC SERVICE LOADS, tons [b] f'_c			
		AREA (in^2)	WEIGHT (plf)	MOMENT OF INERTIA (in^4)	SECTION MODULUS (in^3)	RADIUS OF GYRATION (in.)	PERIMETER (in.)	5000	6000	8000	10,000
SQUARE PILES											
10	SOLID	100	104	833	167	2.89	3.33	73	89	122	156
12	SOLID	144	150	1,728	288	3.46	4.00	105	129	176	224
14	SOLID	196	204	3,201	457	4.04	4.67	143	175	240	305
16	SOLID	256	267	5,461	683	4.62	5.33	187	229	314	398
18	SOLID	324	338	8,748	972	5.20	6.00	236	290	397	504
20	SOLID	400	417	13,333	1,333	5.77	6.67	292	358	490	622
20	11	305	318	12,615	1,262	6.43	6.67	222	273	373	474
24	SOLID	576	600	27,648	2,304	6.93	8.00	420	515	705	896
24	12	463	482	26,630	2,219	7.58	8.00	338	414	567	720
24	14	422	439	25,762	2,147	7.81	8.00	308	377	517	656
24	15	399	415	25,163	2,097	7.94	8.00	291	357	488	621
30	18	646	672	62,347	4,157	9.82	10.00	471	578	791	1005
36	18	1,042	1,085	134,815	7,490	11.38	12.00	761	933	1,276	1,621
OCTAGONAL PILES											
10	SOLID	83	85	555	111	2.59	2.76	60	74	101	129
12	SOLID	119	125	1,134	189	3.09	3.31	86	106	145	185
14	SOLID	162	169	2,105	301	3.60	3.87	118	145	198	252
16	SOLID	212	220	3,592	449	4.12	4.42	154	189	259	330
18	SOLID	268	280	5,705	639	4.61	4.97	195	240	328	417
20	SOLID	331	345	8,770	877	5.15	5.52	241	296	405	515
20	11	236	245	8,050	805	5.84	5.52	172	211	289	367
22	SOLID	401	420	12,837	1,167	5.66	6.08	292	359	491	624
22	13	268	280	11,440	1,040	6.53	6.08	195	240	328	417
24	SOLID	477	495	18,180	1,515	6.17	6.63	348	427	584	742
24	15	300	315	15,696	1,308	7.23	6.63	219	268	368	467
ROUND PILES											
36	26	487	507	60,007	3,334	11.10	9.43	355	436	596	758
42	32	581	605	101,273	4,823	13.20	11.00	424	520	712	904
48	38	675	703	158,222	6,592	15.31	12.57	493	604	827	1,050
54	44	770	802	233,373	8,643	17.41	14.14	562	689	943	1,198
66	54	1,131	1,178	514,027	15,577	21.32	17.28	826	1,013	1,386	1,759

a. Form dimensions may vary with producers with corresponding variations in section properties.

b. Allowable loads based on $N = A_g(0.33f'_c - 0.27f_{pc}); f_{pc} = 700$ psi. Check local producer for available concrete strengths.

16.4.5
Additional Information

The PCI Committee on Prestressed Concrete Piling has published a "Recommended Practice for Design, Manufacture and Installation of Prestressed Concrete Piling" (1993). This report discusses design of prestressed concrete piling, materials, manufacturing, handling, transportation and installation.

Other references on piles include: Falconer and Park, 1983; Sheppard, 1983; Lincoln, 1988; Joen and Park, 1990A & 1990B; Shahawy and Issa, 1992; Kamel, et al, 1996; and Nigels, 1998.

16.5
PILE BENT CAPS

The pile bent is a common form of bridge substructure, particularly for stream crossings or long trestles over larger bodies of water. The pile bent consists of a cap supported by piles driven in the soil. The bent cap is usually a rectangular, cast-in-place, mildly reinforced concrete beam. Some designers have taken advantage of the positive characteristics of precast concrete by using precast bent caps. Precast bent caps have been used in combination with steel H-piles, pipe piles, prestressed concrete piles (including cylinder piles), and even timber piles.

16.5.1
Advantages

There are several advantages to using precast bent caps. The quality of the concrete is superior to field-placed concrete and problems associated with hauling ready-mixed concrete to the site are substantially reduced. Erection of forms, placement of reinforcing steel, and placement and curing of the concrete are replaced with simple erection of the precast cap onto the piles and the connection to the piles. Reduced field labor translates into a substantial reduction in construction time. This was the case for the Sandpoint Bridge (1984), Bonner County, ID, where 177 precast caps were used after the contractor started with, but later rejected, a cast-in-place alternate.

16.5.2
Pile-to-Cap Connections

There are several ways to connect precast bent caps to piles. If steel piles are used, steel plates can be cast into the bottom of the precast bent cap and welded to the tops of the piles. Even though this is an effective connection, it requires field welding in a difficult location. A better method of connecting piles to precast caps involves forming a simple void in the bottom of the cap that fits over and around the piles. The void is then filled with concrete or grout to make the connection. This method has been used successfully with all types of piles. The Bayside Bridge in Pinellas County, FL, used precast bent caps supported on prestressed concrete piles for the low-level approach spans.

For those situations when a moment connection is required between the pile and cap, several methods can be used. For steel piles, studs or reinforcing steel can be welded to the pile and anchored into the grout. For solid concrete piles, reinforcing steel can be anchored into the tops of the piles with epoxy grout and extended into the void.

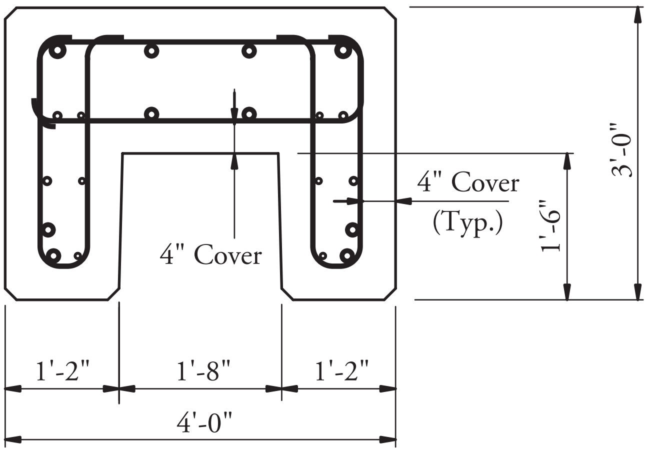
The final installed location of a pile is seldom the exact location called for on the plans, so provisions must be made for pile driving tolerances.

The void in the bent cap into which the pile will fit must be large enough to accommodate the pile placement tolerance and, conservatively, a little more. Adequate clearance must be maintained between the pile and the inside face of the void. The space between the pile and the face of the void must be large enough to adequately distribute the grout.

16.5.3 Size and Weight Limitations

Designers must be aware of limitations related to length and weight of products. These limitations will vary from project to project. The weight per unit length is a function of width. The width, in turn, is typically a function of the size of the piles supporting the cap. The overall weight of the cap must be kept within limits established by the project scope and location. Shipping and erection of a cap at a small stream crossing will probably necessitate a smaller, lighter section than at a large water crossing where shipping and erection can take place with barges. As a rule, smaller projects where product will be shipped overland should be limited to a maximum weight of 50 tons and sometimes, even 40 tons. Projects where larger cranes will be available and shipping weights are less restrictive may have a limiting weight of 70 to 80 tons. One means of reducing the weight of the cap is to fabricate and ship caps in several pieces. Connections can be made by means of a field-cast section, by welding or by post-tensioning the pieces or segments together. By adjusting pile spacing to provide reasonable cap cantilevers in the interior portion of the bridge, the need to make a connection between separate cap segments at a given bent may be eliminated. Another method to reduce weight is to create a void in the cap between the piles. This can be accomplished by using an inverted-U shape, or by casting a hollow void-former in the interior of the cap. **Figure 16.5.4-1**

Figure 16.5.4-1 Typical Inverted-U Pile Bent Cap



16.5.4 Handling

A bent cap is typically considered a continuous beam supported by the piles. Therefore, the span length for a bent cap in its service condition may be relatively short compared to its overall length. However, prior to placement on the piles, the span length is the distance between the lifting locations during handling or the support points during storage and shipping. The cap may be subjected to greater moments and shears during handling and shipping than when in service. These forces must be considered when designing the reinforcement in the cap. Lifting and storage locations should be clearly shown on the shop drawings.

16.6 PIERS

The use of precast concrete used for bridge piers continues to increase steadily. A few recent projects may be used to illustrate this trend.

- The Edison Bridge in Fort Myers, FL, was cited in Chapter 4 (Fig. 4.5.3.2-1). This large water crossing consists of two bridges, one supporting two lanes of traffic plus shoulders and the other supporting two lanes of traffic plus a sidewalk and shoulders. The maximum clearance over the water is 55 ft. The shorter piers were erected in a single day. It took only a maximum of three days each to erect the tallest piers.

- The four precast concrete bridges of the Baldorioty de Castro Avenue in San Juan, Puerto Rico, range in length from 700 to 900 ft (Endicott, 1993). All piers and caps are precast concrete. The four bridges were each constructed and opened to traffic in less than 36 continuous hours from the start of precast erection.
- The Louetta Road Overpass in Houston, TX, (Ralls, et al, 1993) uses precast piers. Each of the superstructure's spread trapezoidal U-beams is supported by an individual precast pier column. These cantilevered columns consist of hollow, multi-sided, match-cast segments. The segments were plant-cast and transported to the site where they were erected and post-tensioned together. See **Figures 16.6-1** and **16.6-2**.

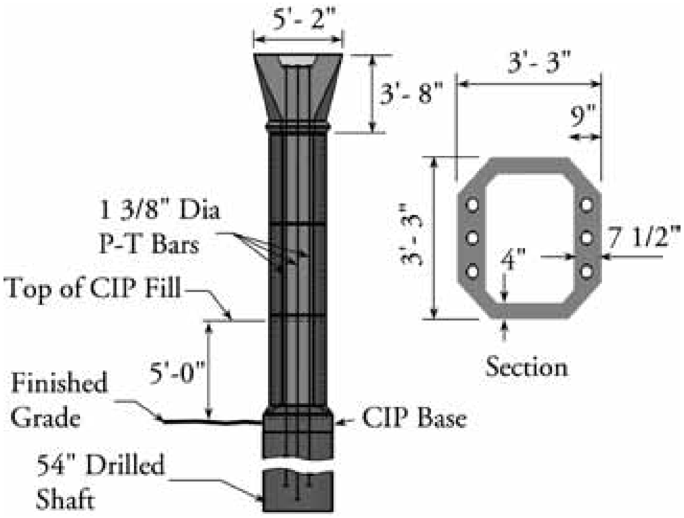


Figure 16.6-1
Louetta Road Overpass Precast Segmental Pier Column

Figure 16.6-2
Columns and U-Beams at Louetta Road Overpass

- The Chesapeake and Delaware Canal Bridge, SR-1, DE, uses 463 box pier segments for 48 columns ranging from 50- to 130-ft tall. The typical box segment measures 18 ft by 8 ft and varies from 4- to 10-ft tall. The segments were stacked and post-tensioned vertically. Joints were sealed with epoxy grout. **Figure 16.6-3** shows a typical pier segment being erected. **Figure 16.6-4** shows several finished piers supporting the cable-stayed bridge under construction. Typically, 100 ft of box pier column was constructed in a day (Pate, 1995).

Figure 16.6-3
Erection of Pier Column Segment

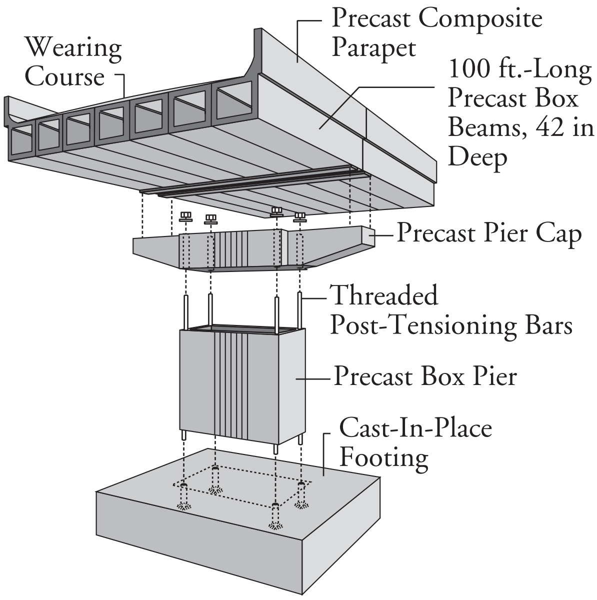
Figure 16.6-4
Finished Pier Columns, C & D Canal Bridge

16.6.1 Advantages

The use of precast concrete bridge piers offers unique opportunities (Billington, et al, 1999):

- Reduced construction time
- Reduced inconvenience to the public during construction
- Lower cost
- Plant-cast quality concrete and enhanced architectural surface treatments.

Figure 16.6.1-1
Pier Schematic, Baldorioty de Castro Avenue Bridges



Significant savings in construction time can be achieved by fabricating precast substructures off site while the foundations are installed. As discussed in Section 16.6, the Baldorioty de Castro Avenue bridges were each constructed exceptionally fast – in just a matter of hours. This unique systems approach to bridge construction is depicted in **Figure 16.6.1-1**. For long water crossings, reduced labor represents not only a direct reduction in the salary paid to the construction workers, but also reduced costs associated with workman's compensation taxes, insurance and exposure. The use of precast caps represents a maximum reduction in the contractor's construction effort because it eliminates the need to erect and strip cap forms. In addition to the time and cost savings, the quality of the concrete is nearly always better than when cast in the field.

16.6.2 Pier Caps

Caps for single and multicolumn piers can be precast in a variety of shapes. For typical grade crossings, simple rectangular sections can be fabricated, shipped to the site and erected on the columns. Inverted-T sections can also be easily fabricated. These simple shapes do not require special forming systems. The reinforcement required is essentially the same as for cast-in-place concrete caps.

For larger caps, such as those used on the Edison Bridge, an inverted-U shape may be more desirable. The inverted-U shape reduces the volume of concrete and therefore the weight for shipping and handling. However, the forming system for U shapes is more complex, as is the reinforcement.

Hammerhead piers can also use precast caps. They consist of a single column and a cap with equal or near equal cantilever lengths. However, these caps are normally fairly large, and special considerations are usually necessary to reduce the weight of these components.

One method to reduce the weight of the cap is to produce the cap in sections and make appropriate connections in the field. Since this can sometimes be complicated, another method is to use a precast concrete shell as a form for the cap. The shell is designed to

Figure 16.6.2-1
Erection of Precast Cap over Column Dowels

support its own weight plus that of the CIP concrete that fills it. While not completely a precast system, this process eliminates the need to erect and later strip forms for the cap. Relatively large caps can be constructed in this manner while achieving manageable weights. For hammerhead piers with smaller caps, a solid cap can be fabricated in the plant, shipped to the site and erected with routine effort. The caps for the piers supporting the guideway for the J. Paul Getty Museum Tram near Los Angeles, CA, were constructed in this manner as shown in **Figure 16.6.2-1** (Josten, et al, 1995).

16.6.3 Columns

Using precast columns in a multicolumn pier usually does not offer the same level of timesavings to the contractor as do precast pier caps, particularly for grade crossings. However, use of precast columns does provide the advantage of high performance concrete associated with precast products. Another advantage of precast concrete columns is the manufacturer's ability to produce uniform architectural finishes. Precast concrete fabricators can typically incorporate form liners into their forming systems more easily and with more uniform results than can be achieved with cast-in-place concrete. The most economical precast column shapes for multicolumn grade crossings are square, rectangular and octagonal.

Precast columns for multicolumn piers at water crossings generally provide a greater potential for time and cost savings. The heavier weights typical of the longer columns required for navigable water crossings are usually not prohibitive because pieces can be shipped by barge and because larger cranes are generally available on marine sites. In addition to the shapes previously discussed, I-shaped columns such as those used for the Edison Bridge can be used to reduce concrete volume and column weight (see Section 4.5.3.2).

Hammerhead piers provide another opportunity for the use of precast columns. These columns are usually fairly massive, and the weight of each component can present a special challenge. Solid rectangular or oval shapes can easily be fabricated, but will be very heavy. By using hollow sections, weights can be reduced significantly. If a solid section is necessary to resist horizontal forces, such as ship impact, the hollow precast column can serve as a stay-in-place form for field-placed concrete. Both solid and hollow columns can be cast in shorter segments and joined in the field. The large flat surfaces of this type of column provide an excellent location for architectural finishes including striations, rustications, reveals and ribs.

The use of precast columns for hammerhead piers presents an opportunity to significantly reduce the volume of field-cast concrete. This may be especially beneficial when existing interchanges are rebuilt. At these locations, the motoring public will be better served by the reduced time of construction. Over water, precast columns for hammerhead piers provide the same time and monetary incentives as the other previously discussed precast pier systems.

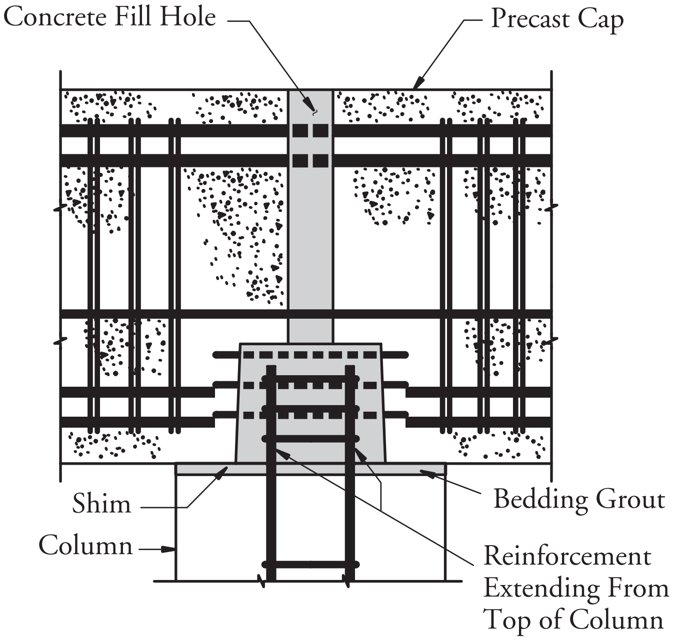
16.6.4 Connections

Connection design, construction details and installation are all important issues. Several methods to achieve pinned or rigid connections can be effectively applied to bridge substructure components. Simplicity and reasonable construction tolerances are primary concerns of both the contractor and precast concrete fabricator.

16.6.4.1 Multicolumn Piers

Most multicolumn piers are designed as rigid frames, with moment transfer between the cap and the columns. However, at typical grade crossings, especially single-level crossings, it is not always necessary to provide a full moment connection between the cap and the columns in multicolumn systems. Often, the design loads can be resisted by the columns acting as cantilevers fixed at the foundations. In these instances, a very simple method can be used to provide a pinned connection at the top. This connection uses a small cage of reinforcing steel that projects from the column into a pocket or void in the bottom of the cap (**Figure 16.6.4.1-1**). This steel can easily transfer the very small moment necessary to keep the cap from rolling off the column. The cap is designed as a continuous beam, simply supported at the columns. The columns are designed as cantilevers about both axes. Although the moment at the bottom of the column is larger than for a comparable rigid frame, the use of minimum steel in the column usually provides the required capacity. In most instances, connections from a precast column to a footing must be capable of transferring moment. This can most easily be accomplished with the use of grouted bar couplers that are described below. Although post-tensioning may be used, the need to anchor the strand or bar in the foundation can present a challenge. Post-tensioning will likely not be cost effective except on very large structures.

Figure 16.6.4.1-1
Precast Cap-to-Column Pinned Connection

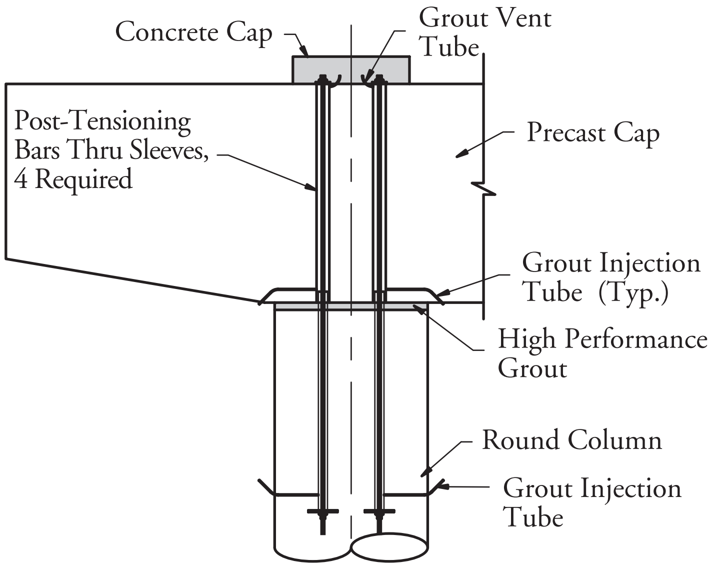


For piers designed as rigid frames, there are two basic methods to make full moment-resisting connections between the columns and pier caps.

16.6.4.1.1 Post-Tensioning

Post-tensioning the cap vertically to the tops of the columns provides the necessary mechanism to transfer moments. This system has been used effectively in a contractor-proposed alternate for a series of two-column piers with solid rectangular precast caps at the SR 10 over Western Flood Plain (Victory Bridge) in Jackson and Gadsden

Figure 16.6.4.1.1-1
Precast Pier Cap-to-Column Connection, Victory Bridge

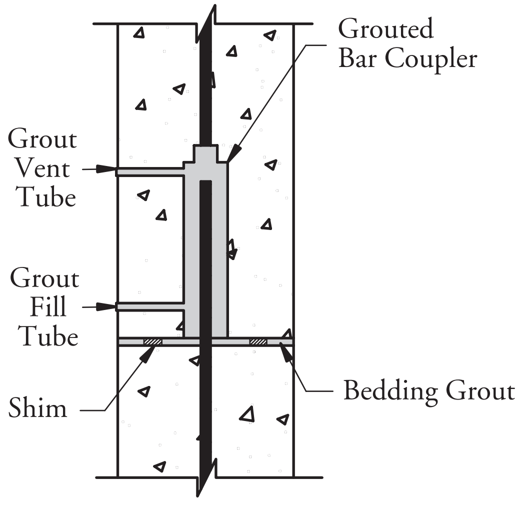


Counties, FL. Post-tensioning bars were anchored in the tops of the CIP columns. The cap was then lowered into place, the bars tensioned, and the ducts grouted (**Figure 16.6.4.1.1-1**).

16.6.4.1.2
Spliced Reinforcement

Another means of providing a moment connection is the use of mechanical splices for reinforcing steel known as splicing sleeves or grouted bar couplers. These devices emulate continuous reinforcement across joints between concrete components. This scheme was used effectively on the Edison Bridge in Florida. The connection used a grouted bar coupler cast into the precast component for each main reinforcing bar. A dowel protruding from the footing or adjoining precast component is inserted into each coupler. When the precast unit is set, the coupler is filled with grout to provide a full-strength splice of the reinforcing steel. See **Figure 16.6.4.1.2-1**. The use of a grouted coupler requires coordination and close tolerances to ensure that the dowels and couplers are in the proper location and orientation. This is easily accomplished with the use of jigs and templates both in the field and in the precast plant. All of the connections for the Edison Bridge were successfully installed.

Figure 16.6.4.1.2-1
Typical Grouted Coupler Detail



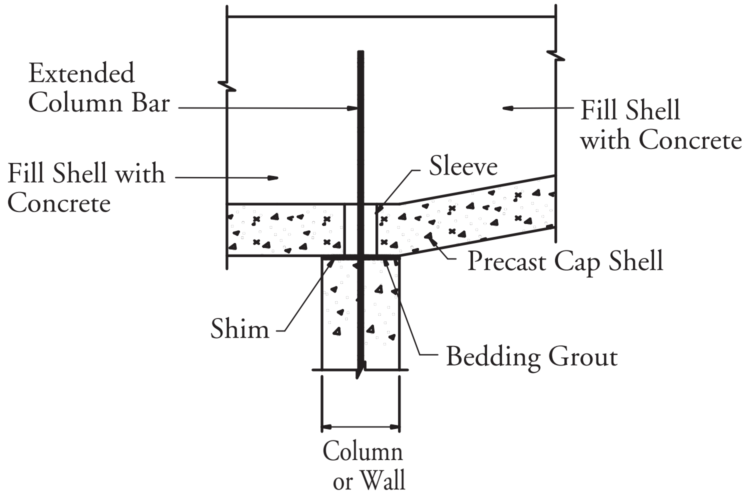
16.6.4.2 Hammerhead Piers

The connection of cap to column in a hammerhead pier must be capable of transferring moments in two directions. As with multicolumn piers, a moment connection can be made using post-tensioning or grouted bar couplers. Since the moments at the column-cap interface are substantially less than at the bottom of the column, the full amount of column steel is not required to secure the cap to the column. For post-tensioned connections, it may be possible to reduce the amount of post-tensioning at the top of the column. When bar couplers are used, a reduction in the steel will reduce the number of couplers required.

If the precast cap shell described in Section 16.6.2 is used, there is a simple means of connecting the column to the cap that does not require post-tensioning or grouted couplers. In this method, a percentage of longitudinal column reinforcing bars is extended through sleeves in the bottom of the shell. These bars are developed when field-placed concrete in the shell cures, thereby providing moment capacity. Refer to **Figure 16.6.4.2-1**.

As previously described, precast columns for hammerhead piers must often be erected in more than one piece. Connections between these segments, as well as the connection to the foundation, must be capable of transferring the full column forces and moments. Post-tensioning can be an effective means of providing these connections, particularly for larger columns. Grouted bar couplers can also be used. With couplers, it is usually more cost effective to use fewer, larger reinforcing bars (#11 or #14) to reduce both the costs of the couplers and the potential for misaligned connections in the field.

Figure 16.6.4.2-1
Precast Hammerhead Cap-to-Column Connection



16.7 ABUTMENTS

Abutments are the end supports of a bridge. There are many variations of abutments in use such as bench or spill-through, stub, deep, etc. A bench abutment is a “resting pad” for the superstructure components with a vertical back wall that retains the soil and supports the approach slab. The abutment may be supported on a spread footing or on piles. A spill-through abutment usually refers to a pile bent where the fill behind the bent slopes down from the bottom of the cap to the channel or roadway shoulder below. The precast version of this system is essentially a precast pile bent cap. Stub abutments and deep abutments refer to those end supports that include a load-bearing wall from the superstructure support to the ground beneath the bridge. The basic difference between stub and deep abutments is the height of the wall.

16.7.1 Applications

Precast abutments can be used effectively almost anywhere that a CIP abutment is used. A precast cap can be used for the spill-through type of abutment as easily as for a typical pile bent. In states where the back wall is made part of the substructure, the back wall could be cast in the plant with the cap, or it could be cast in the field. Stub and deep abutments are essentially walls, for which precast concrete is very effective. The walls can be cast and shipped to the project horizontally, then erected into their vertical position on a foundation, which may be either precast or cast-in-place.

16.7.2 Advantages

In addition to the advantages involving the quality of precast concrete components, the speed of construction is very important. For stub and deep abutments, the use of precast elements eliminates costly and time-consuming forming and curing of walls at the project site. The reduced volume of field-placed concrete may be especially advantageous in remote locations, where there are long distances to ready-mix plants or where concrete delivery is otherwise difficult.

16.7.3 Connections

For spill-through abutments, connection options are the same as those outlined previously for precast pile bents. For wall-type abutments, the connections will be similar to those used for precast wall systems for building structures. Grouted reinforcing bar couplers are an excellent method to make a moment connection at the base of an abutment. A moment-resisting connection between the abutment and the ends of the superstructure can also be achieved to create an integral abutment. This eliminates costly, high maintenance expansion joints. See **Figures 16.7.3-1** and **16.7.3-2**. Other mechanical bar splicing systems require patching of the concrete where the splice is made and may be less desirable because the area will be exposed to earth backfill. Although post-tensioning is an option for stub abutments, it is generally cost effective only for taller systems.

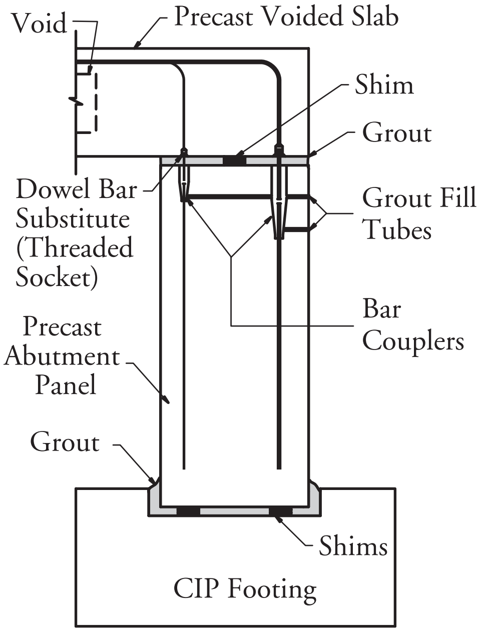


Figure 16.7.3-1
Precast Integral Abutment, Route 9N over Sucker Creek, Hague, NY

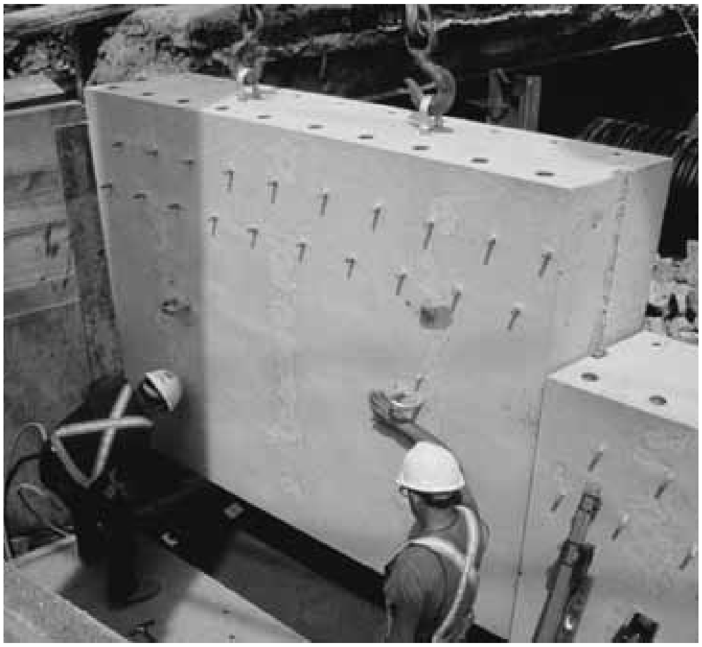


Figure 16.7.3-2
Erection of Abutment Wall , Route 9N over Sucker Creek

16.8 EARTH RETAINING SYSTEMS

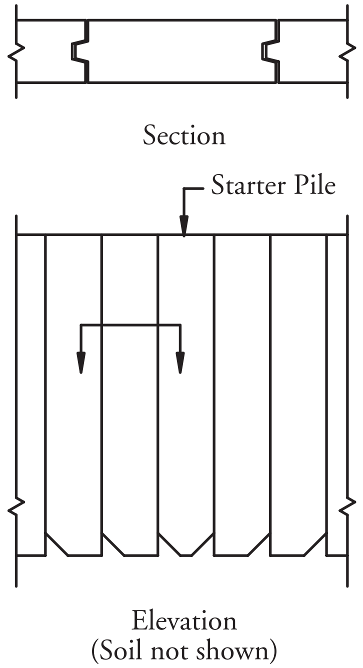
The use of precast concrete components has become popular for earth retaining systems. Concrete sheet piles, gravity retaining walls and mechanically-stabilized earth walls have been successfully and economically installed with an excellent service record.

16.8.1 Sheet Piles

Precast concrete sheet piles, both prestressed and non-prestressed, have been in use for several decades. Applications of sheet piles include both cantilever and anchored bulkheads. Corrosive environments, such as marine installations, exploit the advantage of prestressing to the fullest, since the uncracked section substantially reduces the potential for chloride penetration. The durability of precast concrete in corrosive environments has been proven repeatedly.

Sheet piles are usually fabricated with a concentric prestress force, or a reinforcing pattern symmetric about the center of the sheet. Pile widths vary, but the most economical installations use a single sheet width. Typical pile widths range from 2 ft-6 in. to 5 ft-0 in. Where changes in the alignment of the wall occur, non-prestressed corner pieces are often used. A simple tongue and groove connection between sheet piles assists in aligning the panels during installation and distributes horizontal earth loads between the sheets. It is advantageous to place the tongue of the panel on the leading edge of the sheet, so that the groove of the subsequently placed sheet pile is free of soil. Concrete sheet piles are most easily installed by jetting into place with a water stream. As shown in **Figure 16.8.1-1**, the beveled portion at the leading edge of the sheet pile helps to snug the sheet being installed to the previously placed panel.

Figure 16.8.1-1
Typical Layout, Precast Concrete Sheet Piles



16.8.2 Gravity Retaining Walls

Several precast concrete retaining wall systems have been developed that depend on the weight of the soil being retained to resist overturning. These gravity retaining walls are similar to a traditional CIP wall and footing system. These systems must resist both the horizontal earth pressure as well as an overturning moment. Precast counterfort walls have also been successfully employed.

16.8.3 Mechanically-Stabilized Earth Walls

Using the weight of the soil to resist the horizontal earth pressure, mechanically-stabilized earth (MSE) walls have proven to be very economical systems, especially for large wall areas. MSE walls usually consist of interlocking precast concrete panels that are stacked. A leveling pad of field-placed concrete is used to insure the proper elevation at the bottom of the wall. Horizontal straps connected to the precast concrete panels resist the horizontal earth pressure. The straps extend into the earth fill behind the wall. Strap lengths are determined by the supplier, and are governed by the height of the wall, surcharge loadings and the soil properties of the backfill. Most MSE wall systems are proprietary.

16.9 RAILINGS

Precast bridge railings, also known as parapets or barriers, have been used very successfully. The reduced time used to install the precast product increases the cost effectiveness of the system. The concrete is more durable and can be made more attractive than most CIP systems.

16.9.1 Connections

There are two typical connections used between precast railings and bridge decks. In one system, threaded reinforcing bars project from the bottom of the railing through the deck and are secured with washers and bolts. This system requires careful coordination between the contractor and the precast railing producer to ensure proper location of the holes in the deck. A second type of connection requiring additional field labor uses shorter dowels projecting from the bottom of the railing. These dowels are set with adhesive anchors into holes drilled in the top of the deck. Crash testing of either of these connection systems may be required.

16.10 CULVERTS

When small stream crossings require greater hydraulic capacity than can be provided by circular conduits, concrete culverts provide an excellent alternative to small bridge structures. Precast concrete culverts provide an option that includes all the advantages associated with quality concrete and speed of construction. Precast culverts are especially attractive if stream flow must be maintained during construction. Precast concrete culvert installations include boxes and three-sided systems, placed with single cells or multiple cells to gain greater hydraulic capacity.

16.10.1 Sizes

Precast culverts range in size from small boxes to three-sided systems that span more than 60 feet. As with most precast components, the maximum size is limited by weight and vertical and horizontal clearances when being transported. By placing multiple cells side by side, the hydraulic capacity is virtually limitless. Precast systems can be used anywhere CIP box culverts are feasible and as an alternative to a low-level bridge.

16.10.2 Standards for Design

In the *Standard Specifications*, loadings on culverts and requirements for footings are contained in Section 6. Article. 17.7, contains design requirements for precast reinforced box culverts. Article 17.8 provides design requirements for precast, reinforced concrete three-sided structures.

Concrete design in the *LRFD Specifications* is contained in Section 5. For culverts that are under two or more feet of fill, special considerations for the shear design of culvert slabs are presented in Article 5.15.5.1. The soil-structure aspects of culvert design are contained in Section 12.

AASHTO and ASTM Standards contain designs for box culverts with heights and spans to 12 ft. The standard designs are based on specific concrete strengths and use welded wire reinforcement with small concrete cover. Some agencies have referred to these standard sections for use on projects, but specify increased cover for the reinforcing steel. These standards also address the fabrication and installation of precast box culverts.

AASHTO M273 and ASTM C850 address the use of precast box culverts with less than two feet of earth between the driving surface and the top of the culvert. AASHTO M259 and ASTM C789 govern where the earth cover is greater than two feet. The ASTM Standard C1433 covers both conditions.

16.10.3 Three-Sided Culverts

When the span of a box culvert becomes large, the use of a three-sided culvert is an attractive alternative. These systems consist of a top slab and vertical walls with an open bottom. Three-sided culverts are generally supported on spread footings, which can be either precast or CIP. Infrequently, this system has been installed on pile-supported foundations. Some three-sided systems rely on the horizontal earth pressures to help support the vertical load on the structure. Other systems are rigid frames, supporting loads with only the structure. These systems are generally proprietary and are manufactured regionally by precasters throughout the country. All have standard designs for various applications and loadings.

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