Precast Framing System Provides Innovative Solution to Modernization of Shipbuilding Facility

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An historic world-class shipyard, Bath Iron Works — a subsidiary of General Dynamics and a major builder of complex, technologically advanced naval vessels — required a significant facility modernization and shipway expansion to meet contract production deadlines. A value-engineered precast concrete redesign replaced the original cast-in-place plan for the pile-supported open wharf platform. An extensive precast concrete framing system provided the most efficient and durable solution to construct this large overwater shipbuilding platform in the harsh conditions of coastal Maine. Innovative detailing and a flexible precast redesign were key to meeting the owner's accelerated schedule for critical shipbuilding capabilities. Moreover, the precast system enabled the contractor to overcome daunting site conditions, including a high mean water level, cold weather, tidal cycles and currents, strong winds, and the variable geotechnical substrate for this fast-track project.

Overwater construction in a marine environment presents challenges not found in typical building projects. These challenges are compounded when the facility is located on Maine's rugged coast, requires an accelerated schedule, and has a finish grade just 6 ft (2 m) above mean high water. Under difficult site conditions, innovative design is required to successfully meet the needs of both owner and contractor.

The modernization of the major shipbuilding facility at Bath Iron Works (BIW) is known as the Land Level Transfer Facility. This expansion project creates a more efficient and economical shipbuilding facility and provides the owner with the capability to construct, repair, and retrofit large ships on a level platform rather than a traditional inclined shipway or floating dry dock.

The Land Level Transfer Facility, a $240 million project, includes a 15 acre (6 ha) land level platform for ship assembly and a 750 ft (230 m) floating dry dock for ship launch and retrieval. The shipbuilding platform consists of two distinct components: a 10 acre (4 ha) retained-fill structure inside a steel sheet pile cofferdam, and a 5 acre (2 ha) pile-supported open wharf platform constructed just outside the line of cofferdam cells. The wharf is the subject of this article.

The open wharf supports the outermost of three new parallel shipways flanked on each side by a craneway. The overall dimensions of the open wharf are approximately 250 ft (76 m) wide by 850 ft (260 m) long. Fig. 1 shows a schematic layout of the shipyard.

Supporting the new westernmost Shipway 1 is the retained-fill portion of the facility. Shipway 2 is situated in the middle of the new facility and is supported by the sheet pile cofferdam. Shipway 3 is located on the pile-supported open wharf platform east of the existing fill area. An aerial view of the completed shipyard shows the new facility's first keel assembly under way on Shipway 1, with the new floating dry dock visible in the foreground (see Fig. 2).

PROJECT CHALLENGES

The open wharf was extremely challenging for all parties involved for a variety of reasons. Bath Iron Works had contracted to build several new ships for the United States Navy based on a long-term schedule that could only be met with the production capabilities of the completed facility. (See sidebar, "Distinguished Shipbuilding History," p. 29.) The harsh coastal Maine winter climate was an addi-

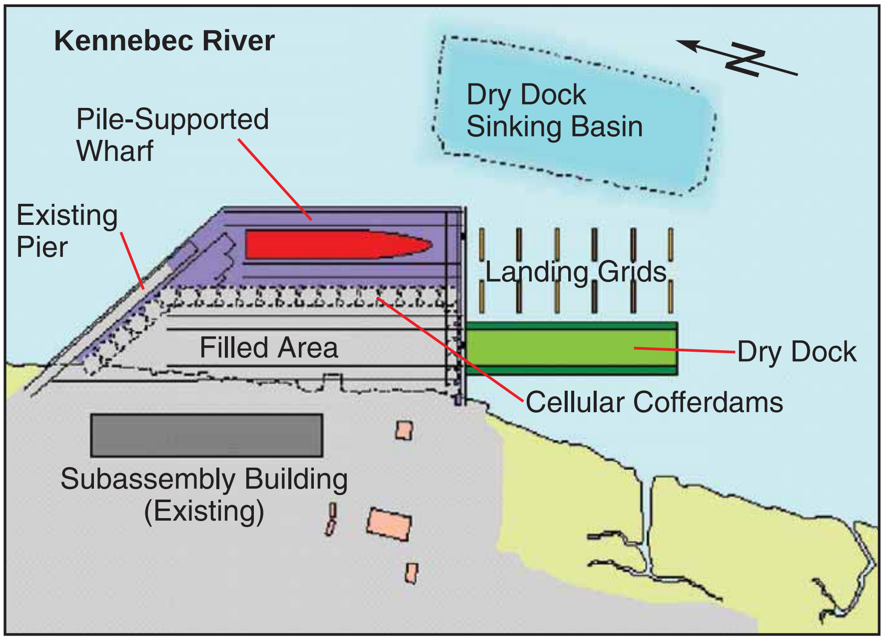


Fig. 1. Schematic site plan of Bath Iron Works shows the existing shipyard and construction of new shipbuilding facilities, including the precast pile-supported open wharf structure.

Fig. 2. Aerial photo (looking north) of the completed shipyard expanded facilities in operation. Photo courtesy: Bath Iron Works.

Fig. 3. Coastal Maine in winter presents harsh weather conditions for marine construction. The average low temperature for December in coastal Maine is about 15 F (–10 C). Photo courtesy: Guy F. Atkinson Construction Company.

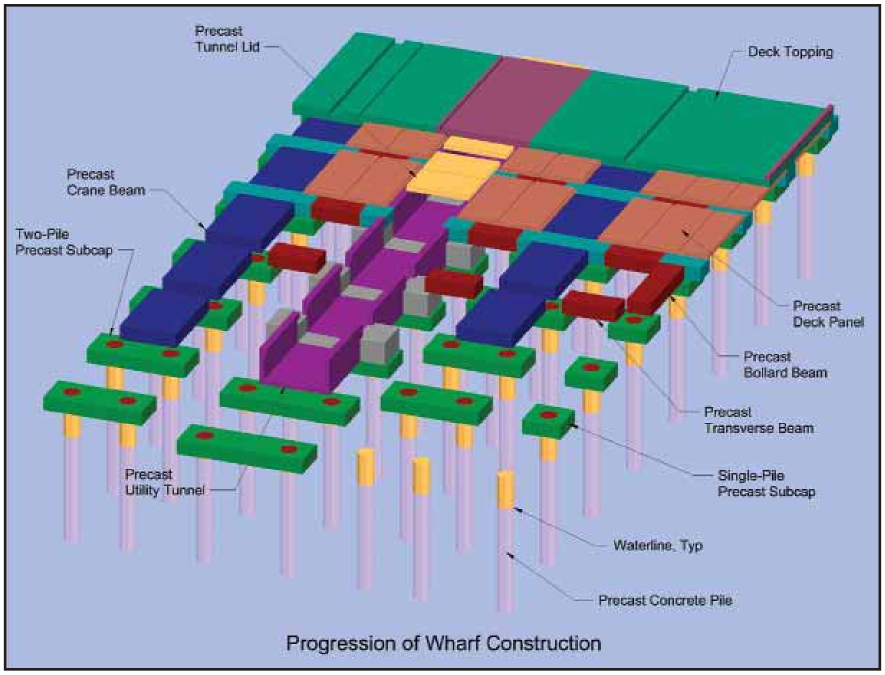


Fig. 4. Block diagram of basic components of the pile-founded open wharf system. Precast concrete units provided design flexibility for special utility vaults and complicated structural geometries.

tional challenge, where strong winds, snow, and ice floes routinely shut down marine construction (see Fig. 3). Finally, the overwater construction was impacted by the need to set the finish grade of the new structure at the same elevation as the existing land-based shipbuilding facility, nominally 6 ft (2 m) above high water, thus submerging portions of the superstructure framing with each tidal cycle.

The preliminary design for the open wharf consisted largely of cast-in-place elements supported on concrete-filled steel pipe piles. The prime design/build contractor, Clark Builders of Maine, LLC, and its marine work subsidiary, Atkinson Construction, immediately saw that a precast concrete framing system would provide a more suitable means to meet schedule demands and maintain productivity in the aggressive environment. Atkinson Construction contracted with BERGER/ABAM Engineers Inc., a consulting engineering firm specializing in the design of marine structures, and initiated a value-engineered redesign of the open wharf structure utilizing precast concrete components to the greatest extent possible.

KEY DESIGN CRITERIA

The following elements were included in the scope of the project:

- Uniform shipyard platform live load: 800 psf (38.2 kN/m^2).
- 471 ton (4190 kN) total working capacity ship unit transporter: two lines of eight axles for a total of sixteen axles, with four tires per axle. Maximum axle load of 72.6 kips (323 kN).
- 790 ton (7030 kN) total working capacity ship unit transporter: two exterior lines of nine axles and one interior line of six axles for a total of twenty-four axles, with four tires per axle. Maximum axle load of 79.6 kips (354 kN).
- 90 ton (800 kN) mobile crane: maximum outrigger load of 187 kips (832 kN) on a 28 in. (710 mm) square pad.
- 300 ton (2700 kN) gantry crane: equivalent working crane rail load of 38.1 kips per lineal ft (556 kN per lineal meter).
- Shipway loads: 600 tons (5400 kN) at 12 ft (3.7 m) on center, applied as two equal loads of 300 tons on each side of shipway centerline, or an equivalent working load of 50 kips per lineal ft (730 kN per lineal meter).

PRECAST MODULAR FRAMING SYSTEM

The redesigned wharf represents what is possibly the largest pile-founded wharf of its kind to have an entirely precast framing system. The redesign includes a foundation of precast, prestressed concrete piles framing into precast concrete subcaps, which in turn support precast concrete transverse and longitudinal beams, utility tunnels, utility vaults, and deck panels (see Fig. 4). Precast concrete elements not only economize and accelerate construction, but they also provide the flexibility to form special vaults, abrupt angular changes, and other difficult closures and connections in a controlled environment (see Figs. 5 to 8).

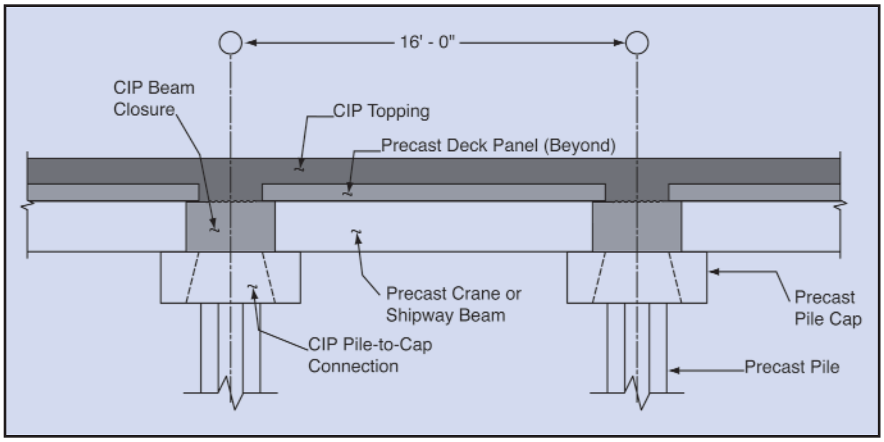


Fig. 5. Typical precast framing and integrated deck system.

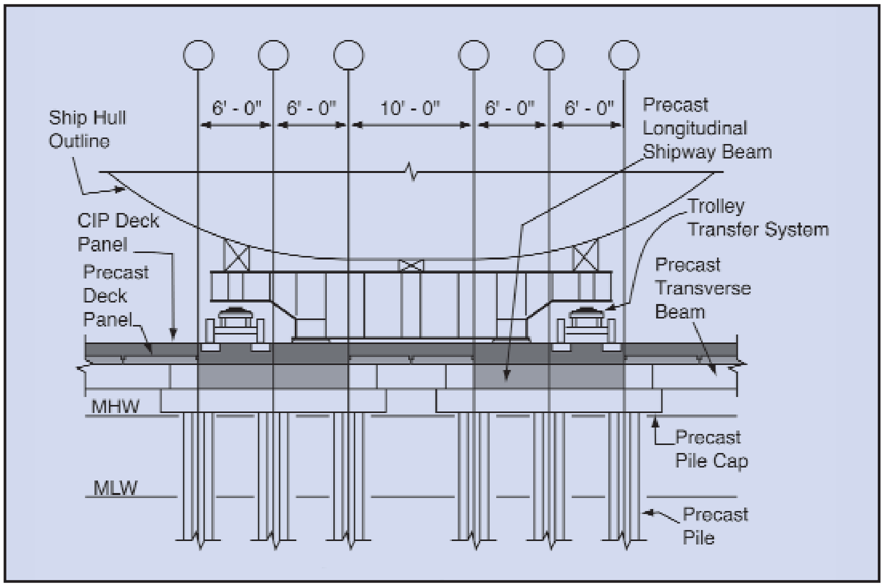


Fig. 6. Section at shipway showing shipbuilding and transfer systems.

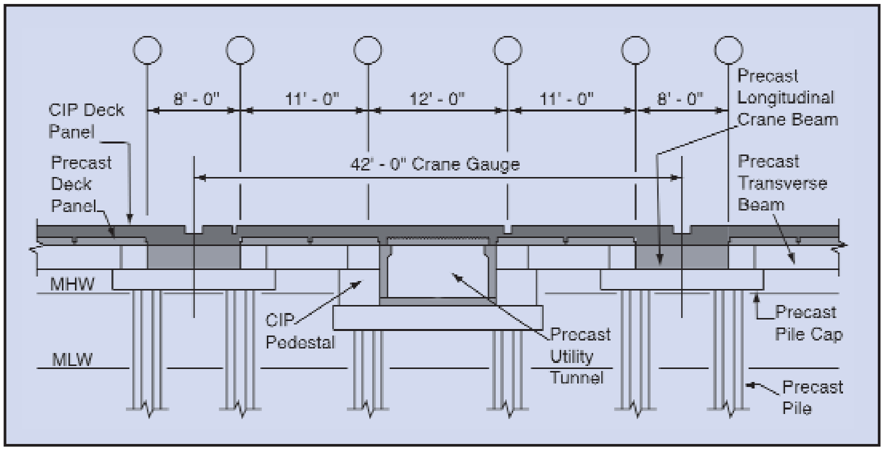


Fig. 7. Section at craneway and utilidor.

The use of precast pile caps represents a departure from the more common construction method utilized in the marine construction industry. Typically, the pile caps are cast in place to provide a measure of pile location tolerance and to simplify the detailing of the beam that completes the pile bent in the transverse direction. In this case, a carefully detailed precast subcap was utilized, which when erected onto and connected to the pile became a monolithic extension of the pile.

This precast subcap (see Fig. 9) was designed to function as a staging platform on which precast transverse beams are erected, which in turn support precast deck panels that span in the longitudinal direction, and longitudinal precast beams that support crane or shipway loads. Once these beams are integrated with each other and with pile reinforcement projecting from the subcap, the structural framing transfers load to the pile as if the subcap no longer existed. With proper detailing, the structural system at this stage is the same as if the transverse beam had been a continuous cast-in-place member.

An additional benefit of the precast subcap system was seen in the case of the deeper precast longitudinal beams supporting the heavily loaded craneways and shipway. Due to the added beam depth, these locations would have required a local lowering of a traditional cast-in-place pile cap. A precast subcap provided the ability to erect these beam members at the same elevation as the transverse precast beams, creating a deep composite section after placement of all cast-in-place concrete as well as an efficient two-way grid beam system to help distribute crane and shipway loads to more piles. Additional detailing coordination was required to ensure that four precast members could land on a single cap without interference of the projecting reinforcing bars or pile dowels (see Fig. 10).

Specialized precast sections had to be developed to accommodate the extensive utilities system required for

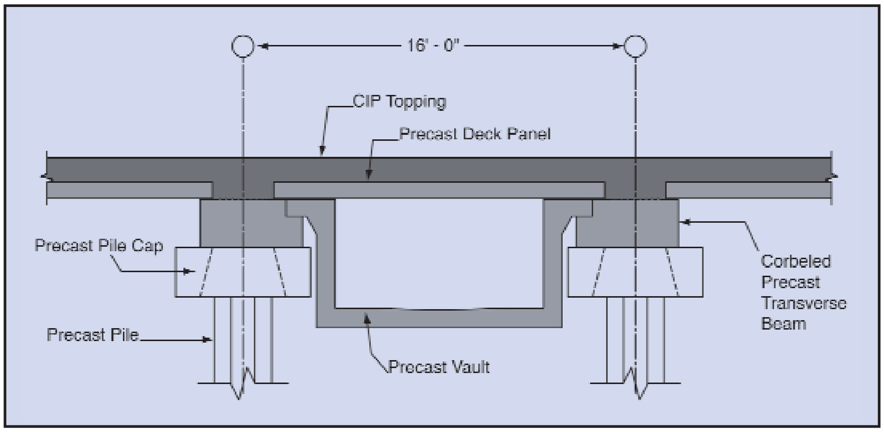


Fig. 8. Typical precast concrete utility vault and connection detail to transverse beam showing clearance of pile cap.

Fig. 9. Precast pile subcaps in staging yard. Careful detailing of subcaps translated into a smooth integration and connection with deck and pile elements.
Photo courtesy: Guy F. Atkinson Construction Company.

shipbuilding. A number of utility tunnels and vaults, including those for water, sewer, electrical, steam, compressed air, and welding gases, were incorporated into the framing scheme.

A commitment to the alternative precast design on the part of the mechanical and electrical designers was required because many of the vaults and tunnel sections had to be redesigned in order to fit within the standard precast framing modules. Much of the benefit of the precast alternative might have been lost without this special attention to detail due to the difficult overwater forming and coordination required at each of the numerous vault and tunnel locations.

Mean high water elevation is approximately 3 ft (1 m) above the tunnel cap soffit, or 1 ft (0.3 m) above the tunnel soffit. Although precast components aided the contractor greatly in sequencing the work at these elevations, the contractor needed to coordinate work in these locations with the diurnal tidal cycles, and special attention to the small closures in this area was still required. The transverse beams were detailed to support both the vault and the deck panels/vault lids, and arranged so that the vaults hung from the transverse beams yet still cleared the sides of the pile caps (see Fig. 11).

Effective waterproofing details were critical for openings and connections of the precast concrete elements that would be repeatedly submerged in seawater. Epoxy-coated reinforcing bars were used in the utility trenches to minimize corrosion in the brackish environment, and special bentonite waterstops were used at all utility tunnel construction joints and closures located below the mean high water line.

It is significant that the precast system was adopted even after substantial completion of the original design and construction on other portions of the project had already begun. Beyond the economic investment required to complete the value-engineered design, the contractor had much at stake in regards to construction schedule. To the extent possible, the redesign was fast-tracked in order to limit the associated scheduling risk. Although extensive coordination was required between the various members of the design team, the final result was fruitful, as the precast framing system enabled the contractor to deliver a more serviceable and durable product to the owner while maintaining a very tight construction program.

PRECAST CONCRETE SOLUTIONS

The primary reason for selecting a precast framing system was the contractor's desire to eliminate all overwater forming, so as to minimize cold-weather concreting which would have been costly and time consuming. As the design team developed the revised framing concepts, other benefits materialized; these included improved scheduling, an optimized pile layout/deck system, improved structural serviceability, and increased durability.

Even with the contractor working on a fast-track schedule, it became clear that construction of the superstructure framing would have to continue through two Maine winters, a time in which it is common for concrete work to be shut down. To maintain the schedule, precast components were produced in an efficient assembly-line sequence, indoors or in warmer months, yet erected throughout the year. By providing protection for the small closure pours and a special cold-climate concrete mix, progress was made even in the coldest weather, when larger-scale cast-in-place work was not feasible. Meanwhile, pile installation continued throughout the year, allowing it to stay ahead of the deck construction schedule.

The selection of precast and precast, prestressed concrete beams and panels allowed the designers to streamline member sizes, effectively simplifying construction. This led to an optimized pile layout, reducing the total number of piles required by providing a layout in which each pile was at or near its 300 ton (270 Mg) capacity. These benefits were seen even while providing the superior serviceability characteristics of a prestressed (and virtually crack-free) soffit in a marine environment. For these reasons, the precast concrete alternative design was mutually beneficial to the prime contractor and the owner.

An important part of the redesign was the improved value of the precast, prestressed concrete piles over steel pipe piles. It was shown that the precast piles had a lower initial cost than the pipe piles as well as a lower life-cycle cost associated with providing and maintaining a corrosion protection system. This translated directly to a major cost savings for the owner, and also provided a more serviceable and durable facility for the long term.

While the original design used both 24 and 30 in. (610 and 760 mm) concrete-filled steel pipe piles, the concrete pile design simplified construction by using one size of concrete pile for all conditions, from the typical areas of the deck to the most heavily loaded areas directly supporting the shipway. The final pile design yielded a first-of-its-kind solid 28 in. (710 mm) octagonal pile with a 300 ton (2700 kN) axial capacity. Piles were spaced as close as 6.0 ft (1.8 m) on center at heavily loaded shipways and craneways, and as far apart as 20.75 ft (6.3 m) in more lightly loaded areas.


Fig. 10. Precast design flexibility meant that the deeper longitudinal craneway beams and transverse beams could be erected at the same elevation. Note that four precast members rest on a single pile cap without interference to numerous reinforcing elements. Photo courtesy: Guy F. Atkinson Construction Company.


Fig. 11. At high tide, precast transverse beam detailing provides support for both the utility vault and deck panel/vault lid while hanging clear of the pile caps below. Photo courtesy: Guy F. Atkinson Construction Company.

A corrosion inhibitor was specified for the pile concrete mix to further enhance the prestressed pile performance in the marine environment. A total of 1315 precast piles varying in length from 30 to 110 ft (9 to 34 m) were fabricated. The precast piles were fabricated by Northeast Concrete Products at their plant in Plainville, Massachusetts, and trucked one by one approximately 170 miles (270 km) to a staging area about 2 miles (3 km) upriver from the site. A marine load-out facility was provided at this location for placement of the piles on scows for pick-up to the pile-driving derrick barge.

For piles longer than 110 ft (34 m), the maximum size deliverable by truck, a composite concrete and steel pile was implemented. These piles consisted of 90 ft (27 m) precast con-

Fig. 12. Precast piles being lofted with specialized rigging. High strength concrete was used in the 28 in. (710 mm) solid octagonal section piles with spiral reinforcement to provide both strength and ductility. Photo courtesy: Guy F. Atkinson Construction Company.

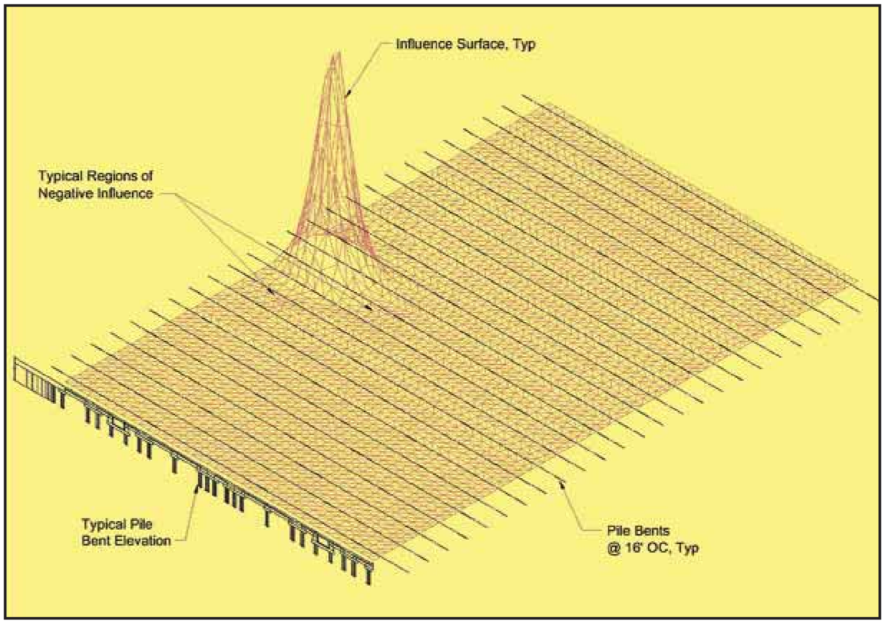


Fig. 13. Pile design influence field loading analysis data representation.

crete piles and employed a steel pipe pile extension located well below the point of fixity (of the soil) to extend the pile into the underlying bedrock layer. Another benefit of the composite design was that it reduced the weight of the pile, providing more flexibility for pile installation. However, special rigging was required to avoid overstressing the pile in the splice area during its lofting into the hammer leads (see Fig. 12).

Approximately 25 percent of all precast concrete piles were installed as composite piles. If all of the piles on the project were laid end to end, they would cover a distance of 22 miles (35 km). Including the steel pipe pile extensions, that distance becomes 25 miles (40 km).

To attain the required 300 ton (270 Mg) axial capacity, a 28 in. (710 mm) solid octagonal section was chosen. A high concrete strength [8000 psi (55 MPa) at 28 days], a circular strand pattern, and a heavy circular reinforcing spiral were selected to provide a fairly ductile pile. In this departure from traditional East Coast construction methods, use of an octagonal shape provided a more efficient section than the typical square pile with a circular strand pattern.

LOAD ANALYSIS AND MODELING

Detailed investigation of the pile-soil interaction was required to satisfactorily bracket the design so that one pile size could be used in all cases. End conditions ranged from fixed-pinned at zero overburden locations to fixed-fixed in deep zones. Since the stiffness of the alluvial material was highly variable from boring to boring, several of the deep overburden locations had to be checked. After analyzing all cases, the resulting maximum effective pile length elected for the design of all piles was 70 ft (21 m).

Extensive three-dimensional analysis was required to demonstrate that the final piling layout would support all possible load combinations associated with ship assembly. This was accomplished by means of a three-dimensional analysis model and a numerical influence field approach. In the model, the deck was subjected to a point load moving incrementally in two directions, creating thousands of individual load cases. Outputting results for all the load cases at any one location provided enough data to create a three-dimensional influence field for a specific pile.

Construction of the three-dimensional numerical influence field was accomplished by post-processing raw computer model output using a customized spreadsheet. The computation of maximum pile loads was made on the same spreadsheet by overlaying numerical footprints representing the various live loads over the field of influence ordinates, much as if the footprints were drawn to scale and traced onto a contour map (see Fig. 13).

Analysis of the non-prestressed transverse beams was performed using the same three-dimensional model as that used for the piling. This enabled a similar influence field approach to determine the maximum stresses on these elements. Longitudinal beams supporting shipway and crane loads were designed using an influence line approach while considering the varying vertical stiffnesses of bents in different locations on the wharf.

Deck panels were designed in the same way for uniform load, but with special plate modeling for concentrated loading. In the case of both panels and crane beams, special consideration had to be given to prestress development and load transfer, due to the relatively short span length [16.0 ft (4.9 m)] between bent centerlines.

The composite 20 in. (510 mm) deck slab was designed to work as a one-way system, although particular attention had to be given to the two-way performance of the precast deck panels at their longitudinal shear keys. Electrical and mechanical conduits located in the cast-in-place topping limited the precast deck panel depth to 8 in. (203 mm), making the panel too thin for a typical shear key detail (see Fig. 14). Because the very large concentrated loads can easily overload deck panels if sufficient shear transfer is not available, special nonlinear finite element analysis was performed to demonstrate that the stiffness of the 12 in. (305 mm) composite topping was enough to substitute for the action of a shear key.

Analysis showed that the topping does transfer enough shear to distribute load to adjacent panels, although with an associated transverse moment and a tendency for the panel joint to open. However, crack widths associated with opening at the joint under the heaviest concentrated loads — generally transient in nature — were computed to be less than the standard accepted criterion for marine construction, or 0.006 in. (150 μm).

A similar analysis was made at the ends of the deck panels, where projecting strands would have made erection difficult because of closely spaced stirrups projecting from the beams. Strands were, therefore, burned flush with the panel ends. However, analysis showed that at bents with the longest and most elastic piles, concentrated loading can create positive moment at the face of support.

Fig. 14. The precast deck panel was limited to an 8 in. (203 mm) depth, too thin for shear key performance. Special nonlinear finite element analysis demonstrated that the composite topping was sufficiently stiff for adequate load transfer.
Photo courtesy: Guy F. Atkinson Construction Company.

Fig. 15. Once the precast piles were driven to refusal in the pre-drilled rock sockets, temporary bracing was installed to maintain position until the final deck integration.
Photo courtesy: Guy F. Atkinson Construction Company.

Additional inelastic analysis demonstrated that while the joint would tend to open at the bottom of the joint in such a case, crack widths would remain small, and reinforcement requirements could be handled with a layer of bars (apart from typical negative moment steel) located just above the top of the panel.

CONSTRUCTION

An important issue for the success of the precast system was control of the tolerances of both the pile location and the erection of subsequent elements. The team adopted the philosophy that all caps and beams must be placed on the grid lines, and that any pile tolerance issues must be adjusted

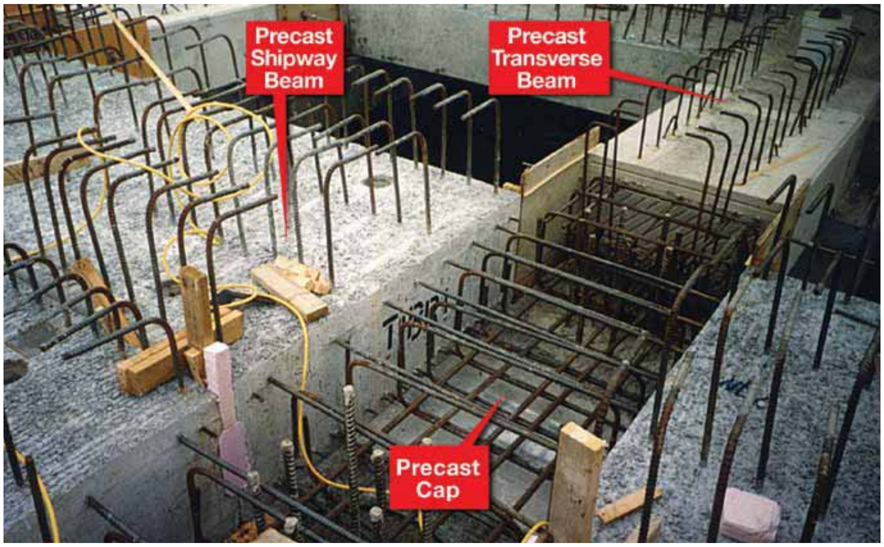


Fig. 16. Closeup of construction showing crane beam closure. Photo courtesy: Guy F. Atkinson Construction Company.

Fig. 17. Careful coordination was required to ensure that bars projecting from piles, subcap, transverse beams and longitudinal beams did not create interferences during erection. Photo courtesy: Guy F. Atkinson Construction Company.

within the pile cap. But because of the highly varying geotechnical profile of the site, pile installation to the required tolerance proved challenging.

Subsurface conditions consisted of loose-to-medium dense alluvial sand deposits overlying dense gneiss. Depth from the final deck grade to the rugged underlying bedrock varied from approximately 25 ft (8 m) to nearly 150 ft (45 m), while the overburden depth varied from zero to about 100 ft (30 m). In some cases, the local profile of the gneiss bedrock stratum was found to be sloping much more steeply than 45 degrees.

All of the precast piles were installed from a sophisticated barge-mounted template, which had been guided into position using the Global Positioning System (GPS). Once the barge was positioned, a 36 in. (915 mm) diameter steel casing was lowered and cleaned out down to the rock elevation. A second inner casing was then spun into the bedrock using a specialized drill to create a 30 x 30 in. (760 x 760 mm) minimum socket. After the hole was flushed clean of debris, the pile was lowered into position, the outer casing extracted, and the pile proofed by driving to refusal. Once the piles were proofed, temporary bracing was provided until the piles and following deck elements were fully integrated (see Fig. 15).

Rather than shift a subcap to accommodate an improperly positioned pile (which would in turn require the shifting of subsequent precast elements and likely cause erection interferences) sufficiently large voids were provided in the subcaps. Then, if the piles were not within the strict 3 in. (76 mm) tolerance limits, special and fast-tracked coordination between the contractor, the design team, and the precaster began.

The team produced a custom precast subcap designed to resist the higher unbalanced loads, yet still provide the standard bearing surfaces so that follow-up work was unaffected. In a few cases, special cast-in-place modifications were required, but in general the precast system proved to be readily adaptable in the field.

The additional coordination effort spent on the design and construction of the piles and caps began to pay off during the construction of the superstructure. Erection of the precast beams and deck panels proceeded very quickly because the caps were kept to within the nominal positioning tolerance — this despite the fact that some of the closures became crowded with reinforcement projecting from all four horizontal directions as well as vertically from the pile heads.

The beam ends essentially created the side forms for the closure pour. Additional formwork was only required to close the gaps at the corners of the beams, and the precast subcap provided an efficient platform to support this work. Once these closures were made, the precast deck panels were placed, followed by the final deck topping (see Figs. 16 and 17).

The erection of the various utility

Fig. 18. Aerial view (looking west) shows construction sequence at the Land Level Transfer Facility. The total project added 15 acres (6 ha) of the modern shipbuilding facilities in Bath, Maine. Photo courtesy: Bath Iron Works.

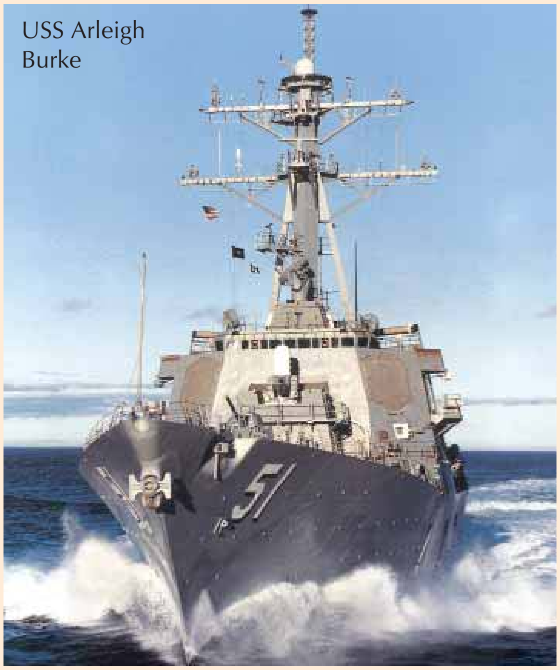
DISTINGUISHED SHIPBUILDING HISTORY

by **D. Joseph Comeau, Jr.**
Manager of Facility Engineering, BIW

In the 1840s, The Bath Iron Works in Maine began producing the finest steel-hulled ships in the world. The year 1890 saw BIW winning contracts for two steel-hulled gunboats, initiating a fruitful relationship between BIW and the U.S. Navy which continues to this day. Over the last century, BIW has provided battleships, frigates, cruisers, and destroyers for the Navy. Since the 1950s, BIW has served as the lead shipyard for ten surface ship classes produced by the U.S. Navy, more than any other U.S. shipyard. In 1995, BIW was purchased by General Dynamics, further enhancing the company's technological expertise and capabilities.

Today, BIW, the second largest private employer in the State of Maine, builds AEGIS Destroyers — the most advanced and capable warships in the world. With the completion of a facility modernization in 2001, BIW became a state-of-the-art shipbuilding facility. These improvements will enable the company to remain the "best value" shipyard in America, offering unprecedented productivity, quality, and affordability to its customers.

Two major milestones in BIW's long history are worthy of mention:



USS Arleigh Burke

- Between 1940 and 1945, BIW built 82 naval destroyers, totaling more ships than the production of the entire Japanese Empire.
- In 1987, the USS Thomas Gates, the first BIW-built guided-missile AEGIS cruiser, was delivered.

Table 1. Precast components for the Land Level Transfer Facility, Bath Iron Works.*

Component	Dimensions	Number of pieces
Precast prestressed concrete piles	28 in. (710 m) octagonal section, of varying lengths, totaling 105,000 lineal ft (32000 m)	1315
Precast concrete pile caps	2 x 5.5 ft (0.6 x 1.7 m) section of varying length, with openings for 1 to 3 pile integration 8400 total lineal ft (2560 m)	669
Precast concrete transverse beams	Main transverse framing element 2 x 3.5 ft (0.6 x 1.1 m) section of varying length 9250 total lineal ft (2820 m)	614
Precast prestressed shipway beams	Primary longitudinal member for supporting vessel construction and transport loading 2 x 6 x 12.5 ft (0.6 x 1.8 x 3.8 m) 2400 total lineal ft (730 m)	192
Precast prestressed crane beams	Primary longitudinal member for supporting crane loads 2 x 8 x 12.5 ft (0.6 x 2.4 x 3.8 m) 2530 total lineal ft (770 m)	206
Precast concrete utility tunnels	Modular unit to fit in deck framing Typical size 4.5 ft deep x 10 ft wide x 12.5 ft long (1.4 x 3.0 x 3.8 m) 1550 total lineal ft (470 m)	121
Precast concrete utility laterals	Special precast utility access tunnel modular unit 14 ft wide x 4.5 ft deep (4.3 x 1.4 m) – length varies 210 total lineal ft (64 m)	20
Precast concrete utility vaults	Provided for electrical, mechanical, sewer, oil-water separation, and crane power Modular design to fit in framing system Size varies, typically 5 ft deep x 6 ft wide x 12.5 ft long (1.5 x 1.8 x 3.8 m)	39
Precast prestressed concrete deck panels	Main deck element – structurally composite with concrete topping Typical size 8 in. (200 mm) x 6 ft (1.8 m) x 13.5 ft (4.1 m) long, varied to suit deck geometry 22,930 total lineal ft (6990 m)	1699
Precast concrete utility tunnel lids	Similar to deck panel, with some lids removable for tunnel access Typically 8 in. x 6 ft x 9 ft long (200 mm x 1.8 m x 2.7 m) 2030 total lineal ft (619 m)	226
	Total pieces	5101

* Total dimensions for this pile-supported structure were 920 ft long x 258 ft wide (280 x 79 m), amounting to 220,660 sq ft (20500 m^2), or 5.1 acres (2.1 ha).

Table 2. Project cost data.

Item	Cost
Cost of cranes and equipment	$60 million
Cost of precast open wharf platform	$25 million
Cost of retained-fill structure and other work	$155 million
Total project cost	$240 million

Table 3. Project timeline.

Project stage	Time
Completion of preliminary design	October 1998
Start of precast design	November 1998
Start of precast manufacture	March 1999
Start of pile driving	March 1999
Completion of precast design	April 1999
Start of precast superstructure erection	July 1999
Completion of pile driving	April 2001
Completion of project	July 2001

vaults and tunnels went quickly for the marine contractor as well as the mechanical and electrical subcontractors (see Fig. 18). The modular drop-in design allowed for the sections to be quickly turned over for utility installation, helping keep all aspects of the project on schedule. Again, this improved construction schedule more than made up for the redesign efforts required of each of the various trades. At times, over six barge-mounted and crawler cranes were required to maintain the accelerated construction schedule (see Fig. 19).

The sheer magnitude and complexity of the completed project is a noteworthy achievement in itself. A combined total of 5101 precast concrete members were produced and installed, including 42 main product types and an even larger number of subcategory elements (see Tables 1, 2, and 3). Due to the size and scope of this project, the work was necessarily divided among three precast manufacturers (see “Credits”).

CONCLUDING REMARKS

The single most important aspect of the project is the benefit realized by the owner and the contractor due to the adoption of the precast framing system. By maintaining a fast-track construction schedule despite difficult working conditions, the contractor was able to help the owner successfully meet critical deadlines for vessel con-

Fig. 19. Overview of project showing numerous barge-mounted cranes operating at the Bath Iron Works construction site.

tract construction. At the same time, the owner has been provided a modern facility with superior serviceability and durability that will fulfill the shipbuilding production needs for its 50-year service life and beyond.

The Bath Iron Works – Land Level Transfer Facility is an excellent demonstration of how a precast concrete system provides flexible, innovative, and cost-effective solutions to challenging site and schedule issues faced by the owner and the contractor, particularly in a design-build scenario.

ACKNOWLEDGMENTS

The authors wish to express their appreciation for the efforts of Phillip Sheridan, project engineer for Guy F. Atkinson, and his construction engineering team, whose coordination ensured successful completion of the complicated precast system. The authors also wish to thank McCoy Butler of Moffatt & Nichol Engineers for his valuable input during the design and construction phases of the project.

CREDITS

Owner: Bath Iron Works, Bath, Maine, a Division of General Dynamics, Falls Church, Virginia

Prime Contractor: Clark Builders of Maine, Boston, Massachusetts

Marine Contractor: Guy F. Atkinson Construction Corporation, Denver, Colorado

Prime Consultant: Moffatt & Nichol Engineers, Baltimore, Maryland

Open Wharf Consultant: BERGER/ABAM Engineers Inc., Federal Way, Washington

Precast/Prestressed Concrete Component Manufacturers:

- Bayshore Concrete Products, Cape Charles, Virginia, in association with Precast Structures, Inc., Auburn, Maine, for precast/prestressed deck panels, precast/prestressed crane and shipway beams, and precast concrete pile caps.
- Rotondo Precast, Rehoboth, Maryland, a division of Oldcastle Precast, Northeast Group, Bethlehem, New York, for precast concrete utility tunnels and lids, precast concrete transverse beams, and precast concrete utility vaults.
- Northeast Concrete Products, LLC, Plainville, Massachusetts, for precast/prestressed concrete piles.