

# Enhancing Durability with Precast Concrete Structures

*"The structure is our friend, and within limits it is tolerant of our shortcomings. Loads, such as dead, live, wind, earthquake, temperature, and creep, are our enemies. It behooves us to learn the enemy's plan of attack and develop defensive tactics, not always by frontal resistance but sometimes by flanking movement."*

Halvard W. Birkeland  
*Wisdom of the Structure*

by Greg Banks, BergerABAM Inc.

Our aging highway infrastructure has allowed us to witness concrete damage due to corrosion of reinforcement steel, which has led to significant costs in maintenance and repair. As Halvard Birkeland had stated, it is now our duty as engineers to develop strategies and mitigate costs associated with preservation of existing infrastructure. Rising to the challenge, significant efforts have been deployed to develop more durable design strategies. One such effort, developed through the Strategic Highway Research Program 2 (SHRP2), is a service life design approach.

The service life design approach provides a systematic way to assess the service performance of a given structure with the goal to find new and better ways to design structures that will last longer and require less maintenance. The approach considers a wide range of factors such as project location, environmental conditions, materials, and anticipated load demands with the primary objective being to avoid development of degradation mechanisms.

For concrete structures, degradation first occurs when substances from the surrounding environment penetrate into the concrete via cracks and either accumulate over time within the outer concrete layers or penetrate inward toward the reinforcement. Carbonation, chloride penetration, and sulfate accumulation accelerated by cyclic wetting and drying are examples of such means of penetration. After time, the protective layers break down and/or critical levels of detrimental substances are reached and corrosion commences.

The focus of this article is not to go through the service design approach (readers are directed to the references for details), however, to introduce an innovative partially prestressed concrete concept that could be used to enhance the durability of our transportation infrastructure. The concept being introduced stems from research conducted by the U.S. Navy, which invested in

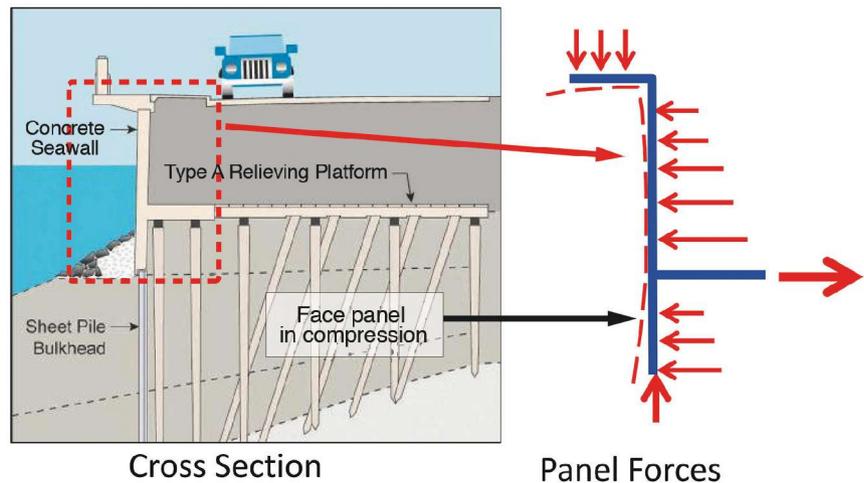


Figure 1. Pacific Northwest pier construction using gravity-induced prestressed concrete with free body diagram showing compression forces on panel face. All Figures: BergerABAM Inc.

a multi-year project with the goal to develop a fully prestressed concrete pier system that minimizes concrete cracking to produce more durable pier structures.

## U.S. Navy Partially Prestressed Concrete Pier Concept

Historically, pier structures in the Pacific Northwest have consisted of reinforced concrete flat slab decks supported by precast, prestressed concrete piles. Due to the significant investment being devoted to maintenance and repair of these structures, the U.S. Navy invested in a multi-year research program with the goal of developing a prototype for fully prestressed concrete pier and sea wall designs with similar features to their existing reinforced concrete pier designs, that would minimize cracking to produce a more durable coastal structure.

## Gravity-induced prestressed concrete.

Due to constructability issues related to the use of post-tensioning in some areas, the age of precast concrete element integration, curing conditions, or other concerns, a fully prestressed (pretensioned with post-tensioned) system using gravity-induced prestressed concrete was developed (Figure 1). This system was developed with the following objectives:

- Reducing the routine dependency on post-tensioning
- Using precast precompressed concrete elements for all structural members exposed to saltwater, thus reducing cracking on the exposed faces
- Improving performance of precast, prestressed concrete elements while simplifying fabrication and installation
- Increasing the modularity of elements to provide the designer with flexibility to configure the pier to meet structural and functional requirements
- Reducing cost to make the new pier concept comparable to current Navy pier designs

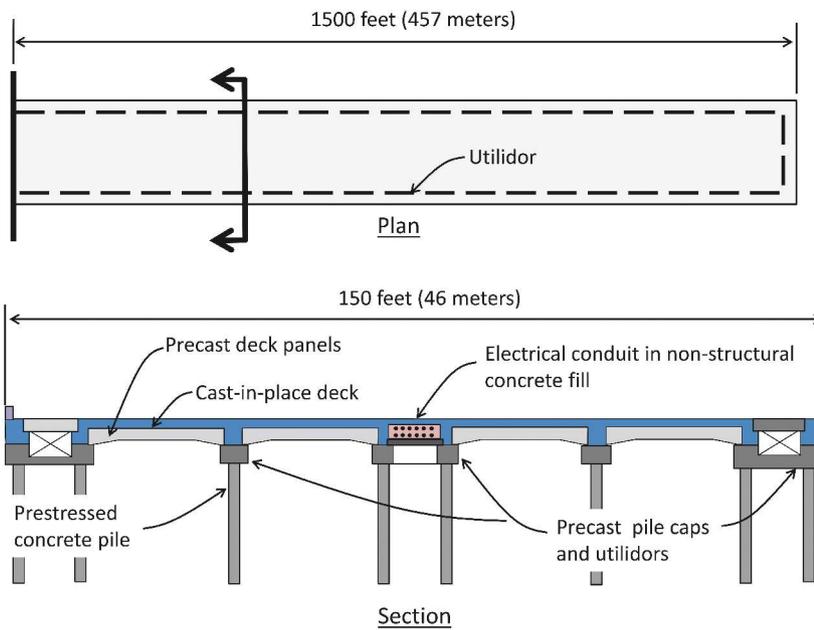


Figure 2. Schematic plan and section of the sample pier.

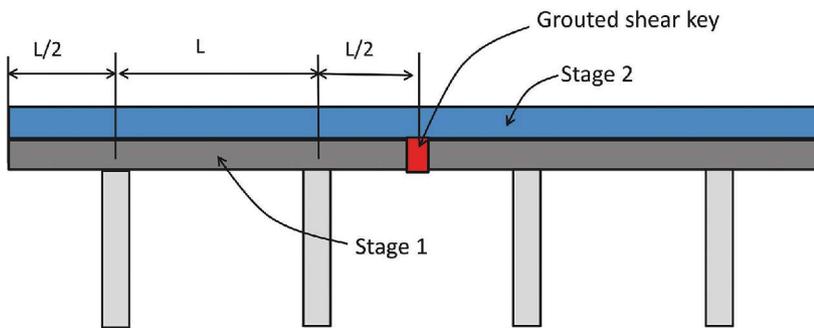


Figure 3. Cantilevered cap beams.

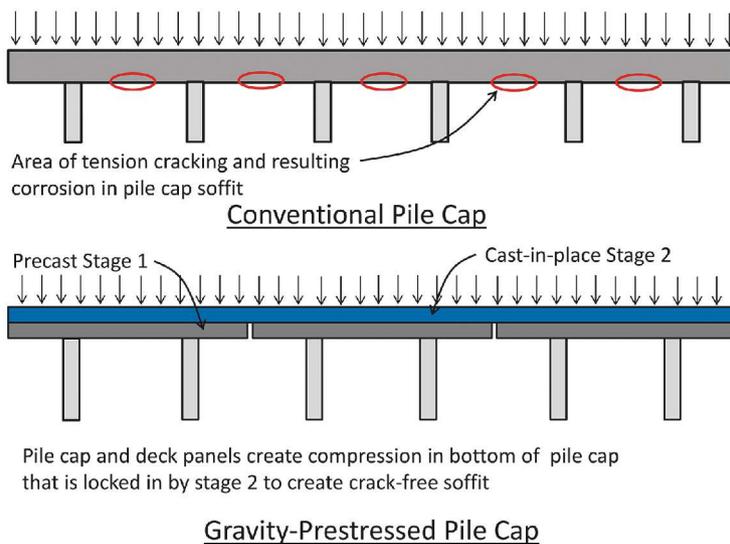


Figure 4. Conventional versus gravity-induced prestressed pile caps.

The partially precast concrete pier system, shown in Figure 2, consists of precast prestressed concrete piles, precast concrete pile caps, and precast concrete deck panels. The elements are integrated with a cast-in-place reinforced concrete topping slab. The precast concrete pile caps, shown in Figures 3 and 4, replace conventional cast-in-place concrete pile caps. The precast concrete pile caps are continuous over two piles with cantilevered segments on each end that extend to midspan of the adjacent bay.

Using the concept of gravity-induced prestressing, the adjacent stage 1 precast concrete pile cap beam elements are not connected before the placement of the deck panels and the stage 2 closure concrete. The dead loads are thus carried by the cap beam segments and live loads are carried on the continuous structure. In this configuration, the bottom of the pile cap will be under compression or low levels of tension under dead and live loads, which will minimize cracking. The stage 2 closure concrete was cast-in-place and contained polypropylene fibers to minimize early age cracking.

## Applicability to Infrastructure

There are many similarities between waterfront pier structures and bridge transportation structures. Concepts applied to one could most likely be applied (at least in concept) to the other. In the current case, bridge structures often contain cast-in-place dropped crossbeams used to support longitudinal precast, prestressed concrete girders spanning between piers. The precast, prestressed concrete pile cap concept developed in the noted U.S. Navy research project could easily be adopted to multi-column bridge structures (Figure 5).

The conventional stage 1 cast-in-place concrete crossbeam would be replaced with a stage 1 precast crossbeam(s) spanning continuously over two columns with cantilever segments extending to midspan of the adjacent column bay. The precast, prestressed concrete girders would then be set and the superstructure diaphragms and bridge deck cast before casting the stage 2 pier diaphragm (assuming a stage 2 pier diaphragm pour exists).

Also illustrated in Figure 5, it would not be hard to imagine applying a similar concept to full-depth precast concrete deck panels spanning transversely between longitudinal precast, prestressed concrete girders. With bridge decks, thought would need to be given to longitudinal tensile forces developing across the transverse panel joints and making

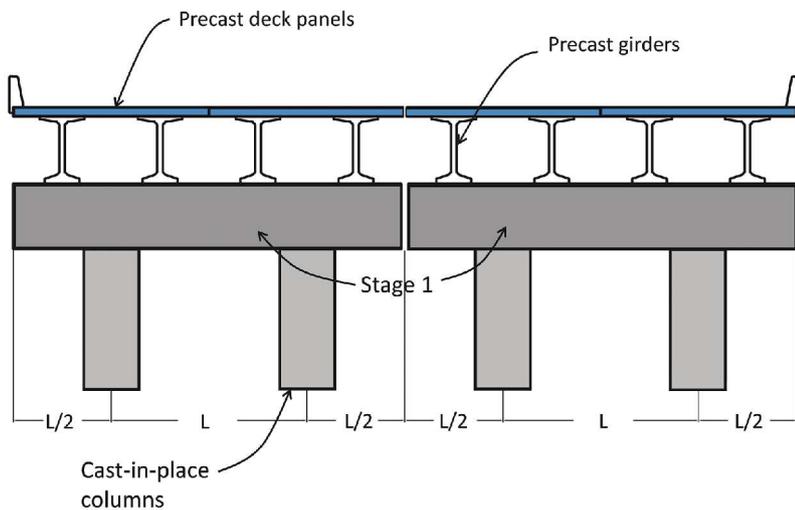


Figure 5. Cross section of a typical multicolumn bridge.

sure residual compression exists across the joint under the design service conditions.

### Closing Remarks

Although the concept of gravity-induced prestressing (or compression on exposed faces) presented is not inclusive to all

structural elements, it is another tool in the toolbox, and another step towards improving the durability of concrete structures. Engineers working with the Navy using prestressed (both pretensioned and post-tensioned) concrete elements have seen reduced cracking. Therefore these structures

have the potential to be highly durable structures exposed to brutal environments by forcing corrosion causing environmental substances such as chlorides to travel through concrete versus annulus spaces created by cracks.

### References

1. Harn, Robert, Michael Oesterle, and Markus Wernli, 2016. *Development of an Innovative, Partially Prestressed Concrete Pier Concept to Enhance the Durability of U.S. Navy Piers*, 2016 ASCE Ports Proceedings: 109-118.
2. Strategic Highway Research Program (SHRP2). 2015. *Durability Assessment of a Bridge Substructure*, August.
3. Birkeland, Halvard. 1978. "The Wisdom of the Structure", *ACI Journal*, 75(4): 105-111. 

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