CETRA[2026] 27-30 May 2026, Bol, Island Brač, Croatia
9th International Conference on Road and Rail Infrastructure

A HYBRID PRECAST–IN-SITU APPROACH FOR PIERCAP CONSTRUCTION IN CHALLENGING INTER-TIDAL ZONES

Sathyanarayanan Dhandapani, Shanthi T, Ramya Dharshanam, Thirunavukkarasu M
L & T construction, India

Abstract

Constructing bridge substructures in intertidal environments poses significant challenges related to access, staging, safety, and construction logistics. The present innovation was developed for a dual-carriageway bridge comprising two independent four-lane carriageways, supported by single-cell PSC box-girder superstructures resting on individual pier caps and cantilever piers. Conventional in-situ construction of pier caps was found impractical due to complex marine formwork, higher manpower requirements, and safety risks associated with working over water. Additionally, the limited load capacity of Temporary Access Bridges (TABs), combined with restricted land access and insufficient tidal draft for barges, made the transportation of full-depth precast pier caps infeasible. To address these constraints, a partially precast pier-cap shell system was adopted. The shells were fabricated in a casting yard, transported within TAB load limits, and erected over the pier columns to serve as permanent formwork. A subsequent in-situ concrete pour completed the pier cap, ensuring structural continuity. This method reduced staging requirements, improved safety, minimized environmental impact, and enhanced overall construction efficiency.

Keywords: precast shell, intertidal zone, temporary access bridge, in-situ concrete, environmental and safety constraints

1 Introduction

Unlike electronics and other consumer products that are manufactured offsite and installed later, civil structures are largely constructed in place, commonly referred to as cast-in-situ (CIS). CIS construction presents challenges at every stage – from material and equipment transportation to final curing – impacting safety, quality, time, environment, and cost. However, with advancements in construction practices, plug-and-play concepts such as segmental bridges and precast structural components are increasingly adopted and integrated at site [1, 2]. Beyond non-structural elements, major components like beams, slabs, wall panels, girders, segmental boxes, and pier caps are now precast. One such initiative involving precast pier caps has been implemented in our project and is detailed below.

2 Description of project

The project is an elevated corridor forming a critical infrastructure link in one of India's busiest metropolitan cities – Mumbai. It constitutes a key segment of the city's north–south coastal corridor. The alignment primarily runs along a creek within the city, connecting the mainland through strategically located interchanges.

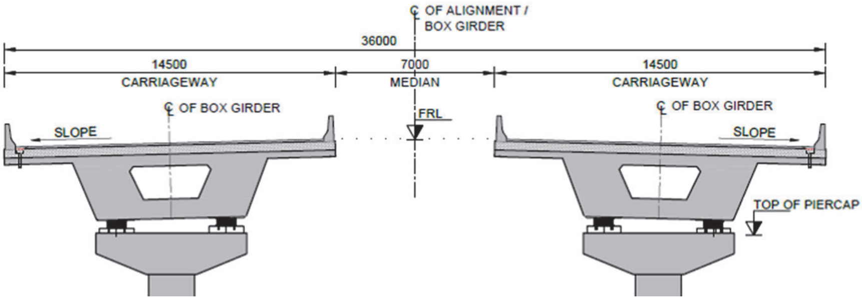

Figure 1 Typical cross section of the Main alignment

The main alignment consists of two independent superstructures, each with a deck width of 14.5 m (figure 1), accommodating four-lane carriageways.

2.1 Superstructure configuration

The superstructure is designed as a 4- and 5-span continuous precast single-cell segmental box girder, with continuity achieved through intermediate diaphragms. Continuous box girders were selected to enhance riding comfort, considering the importance of the corridor in urban connectivity. The box girders are erected using a launching girder (LG). Span-by-span erection is adopted, with temporary supports provided over the piers until continuity diaphragms are completed through in-situ concreting at pier heads.

2.2 Emergency bays

In recent years, emergency bays have become a mandatory requirement in most large-scale, long infrastructure projects. These bays (also referred to as lay-bys) provide a safe zone for vehicles during emergencies, breakdowns, short halts, and vehicle inspections.

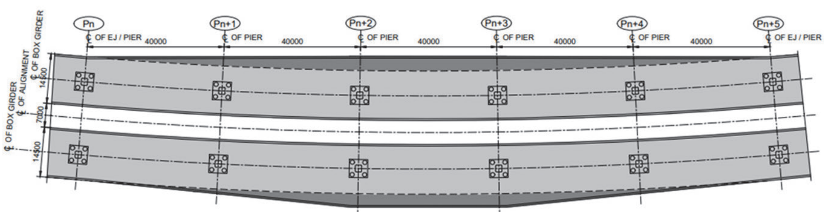

Figure 2 Plan of Emergency Bay (200m length with varying deck)

For the project under discussion, the typical span comprises two parallel carriageways, each 14.5 m wide, separated by a 7 m median. At emergency bay locations, the median width is retained, while the deck width is increased on the outer side to accommodate the additional width required for the lay-bys. Accordingly, the deck width varies from 14.5 m to 18.5 m, and the bays typically extend over a length of about 200 m (figure 2).

2.3 Piercap concept

Recognizing the difficulties of CIS construction in marine environments, the project team adopted a precast piercap solution to reduce in-situ activities. However, there were design level challenges to adopt the precast piercap in the project and is detailed in the below chapter.

3 Barriers for implementation

3.1 Variations in superstructure geometry

Based on client requirements, emergency bays are to be provided at intervals of 1 kilometer along the project. Conventionally, deck widths exceeding 15 m are accommodated using multi-cell box girders or parallel superstructures. However, these approaches require larger pier cap dimensions, resulting in multiple pier cap configurations along the project stretch. To address this, the superstructure was optimized such that the emergency bays adopt the same outer box section as the typical spans, with an extended cantilever of up to 5 m to support the additional deck width (figure 3). The span length was also reduced to maintain overall weight and support reactions within limits. This approach ensured that the pier cap dimensions remained unchanged. Additional benefits achieved include:

- use of the same launching girder, with segment weights comparable to those of typical spans
- reuse of precast molds (for typical spans) with only minor modifications to accommodate the cantilever.

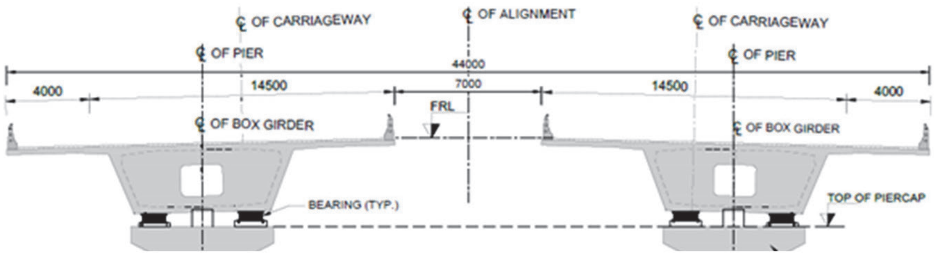

Figure 3 Typical Cross section of Emergency Bay

3.2 Limitations of temporary access bridge (TAB)

Despite minimizing in-situ works, marine construction necessitates the use of barges for material transport. However, during low-tide conditions, barge movement is restricted due to the alignment running close to the creek bank. Hence, a Temporary Access Bridge (TAB) was required. The TAB typically comprises steel decking supported on steel liner piles, with pile lengths governed by loading requirements. In this project, the TAB design was driven largely by the loads from piling rigs and cranes.
Precast pier caps, either factory-produced or yard-cast, were transported to site using specialized trailers and erected using cranes positioned on the TAB. Fully precast pier caps weighed approximately 85 MT, necessitating large-capacity cranes and significant TAB strengthening, leading to increased cost and complexity.

4 Concept development

Construction methodology assessments indicated that any component exceeding 45 MT would require substantial TAB strengthening. Since reducing pier cap dimensions was not feasible, weight reduction through construction-stage optimization was explored. A precast shell with partial in-situ concrete infill was adopted. The shell acts as permanent formwork during construction and satisfies service-stage requirements after infilling concrete. Two options (RCC & PSC) were studied, and the outcome is detailed in table 1.

Table 1 RCC Shell Vs PSC Shell

RCC Precast shell	PSC Precast shell
Tensile forces resisted using conventional reinforcement	Tensile forces resisted using prestressing steel
Majority of reinforcement cast in yard; limited top reinforcement installed on site	Requires specialized equipment and skilled labor
Simplified site operations	Stressing possible only after achieving target concrete strength
Shell weight: ~45 MT	Shell weight: ~40 MT

Although the PSC shell offered marginal weight reduction, the complexity of post-tensioning in a constrained marine environment outweighed the benefits. Considering constructability, logistics, and schedule reliability, the RCC shell option was selected for detailed analysis and design.

5 Analysis and design

5.1 Dimensioning of piercap

The pier cap was designed for service load conditions using bearing reactions obtained from global structural analysis performed in MIDAS. Given the low shear-span ratio, the pier cap was designed using corbel action, considering both service loads and launching girder reactions. The overall pier cap depth was finalized as 1.7 m based on design requirements. Design was performed based on standards published by Indian Roads Congress (IRC) [5, 6].

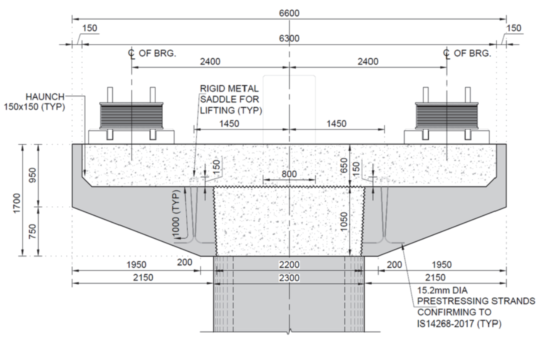

Figure 4 Precast piercap with In-situ fill

Based on the shell weight limitation of 45 MT, dimensions of the precast shell is arrived and the rest of piercap being completed with in-situ fill. Most of the reinforcements planned to be embedded in the shell stage during casting, minimizing the site work.

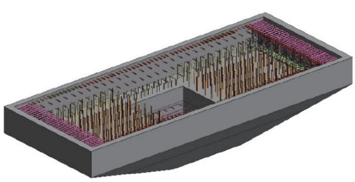

Figure 5 3D View of precast Piercap shell with embedded reinforcement

5.2 Finite element modelling

A 3D solid model (figure 6) with appropriate boundary conditions was analyzed in MIDAS for following conditions:

- lifting operations
- stacking arrangement
- shell subjected to in-situ pour (Wall pressure)
- interface shear due to loading and differential shrinkage.

Stress levels at each stage were ensured to be within permissible limits (refer figure 7 for sample stress check during lifting). Based on the grade of concrete (M60), tensile and compressive stresses in piercap are restricted to characteristic tensile strength (f_{ctm}) and permissible compressive stress in concrete (0.48 f_{ck} i.e. 28.8 MPa). Shell wall checks under infill pressure showed a utilization ratio of 0.2 for 150 mm thick walls, with negligible deflections (figure 8). Differential shrinkage strain of 0.0002 was considered. Interface stresses were found to be approximately 2.5 MPa, well within permissible limits.

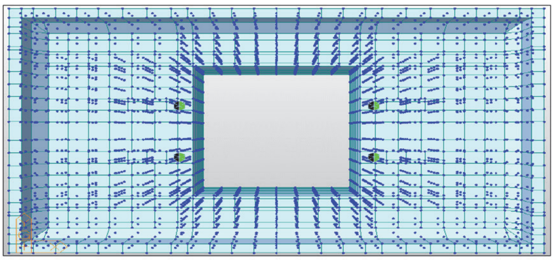

Figure 6 3D FEM model

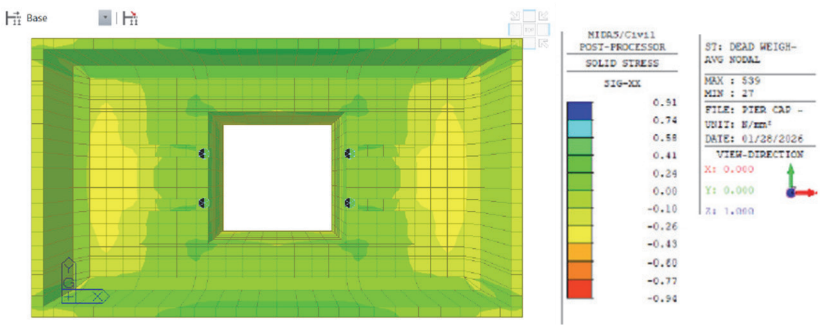

Figure 7 Stresses in Precast Shell for lifting condition

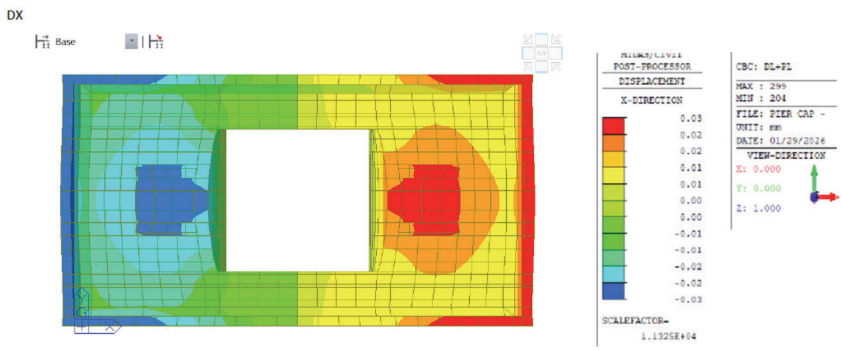

Figure 8 Outward deflections of Precast shell for in-fill pour pressure

6 Performance and sustainability outcomes

The proposed solution delivered significant sustainability and economic benefits:

- Time: Parallel yard casting alongside foundation and pier works eliminated marine formwork and scaffolding, reducing cycle time by approximately 18 days per pier cap
- Cost: While no reduction in permanent materials (concrete and reinforcement) was achieved, the approach minimized marine manpower, eliminated the need for specialized in-situ formwork, and enabled repetitive mold usage, resulting in an estimated 60% reduction in labor
- Safety: With high fatality rates (38 per day, as per the publication of British safety council [3]) reported in the Indian construction industry, shifting critical activities away from marine zones substantially improved overall safety
- Quality: Controlled casting yard conditions ensured superior surface finish, improved curing, and consistent quality
- Environment: Adoption of precast techniques reduced marine ecotoxicity by approximately 60% [4] compared to conventional cast-in-situ construction.

7 Implementation challenges

7.1 Stacking limitations

The unique geometry of the precast shell restricts multi-level stacking, necessitating large storage areas. In constrained sites, a Just-in-Time (JIT) casting and erection strategy may be optimal. Benefits of JIT include:

- reduced storage requirements
- lower handling damage risk
- improved logistics efficiency.

However, JIT demands precise planning, as any disruption directly impacts progress. Alternatively, optimization in terms of shell geometry can be made to enable safe multi-level stacking which offers the same benefits as JIT and reduces the risk on construction progress. Importantly, any modification must preserve the architectural aesthetics of the pier cap, a key client requirement.

7.2 Construction tolerances

Care must be taken to achieve precise alignment for the concrete outlines and reinforcements. Tolerances need to be tight to ensure proper load transfer. Size of precasting unit cannot be so large, as this could lead to logistical issues. Any change during construction stage is almost impossible, as the factory made components cannot be modified. Surface preparation (roughening, cleaning) is essential but hard to ensure consistently. Ensuring proper bonding between precast shell and cast-in-situ concrete is critical.

8 Conclusion

The precast pier cap shell with in-situ infill presents an efficient alternative to conventional cast-in-situ construction for marine infrastructure. By maintaining uniform pier cap geometry and optimizing component weight, the solution successfully addressed challenges related to logistics, Temporary Access Bridge limitations, and superstructure variations. The RCC shell option offered a practical balance between constructability and performance, avoiding the complexities of prestressing while ensuring structural adequacy through detailed analysis. The approach significantly reduced marine activities, leading to improved safety, better quality through controlled casting conditions, and notable time savings. Although challenges such as stacking constraints and tight construction tolerances exist, these can be managed with proper planning and execution strategies. Overall, the methodology demonstrates a scalable and sustainable construction approach, with strong potential for adoption in similar marine and urban infrastructure projects.

References

[1] Chung, C.H., Lee, J.H., Kwon, S.H.: Proposal of a New Partially Precast Pier Cap System and Experimental Verification of its Structural Performance, KSCE Journal of Civil Engineering, 22 (2018), pp. 2362-2370

[2] Salvi, N.A., Barbude., P.R., Rasal., S.A., Rele, R.R.: Design and Analysis of Prestressed Cantilever Pier Caps: For Gravity Loads using CSi Bridge Software, JETIR, 12 (2025), pp. 624-632

[3] British Safety Council (Safety Management), https://www.britsafe.in/safety-management-news/2022/construction-in-india-a-dangerous-business?utm_source=chatgpt.com, 07.10.2022.

[4] Meilak, K., Borg, R.P., Musarat, M.A.: Comparative Life Cycle Assessment of Concrete Elements: Cast in Situ, Semi-Precast and Precast, Buildings 16 (2025), 146

[5] Indian Roads Congress, IRC: 112 – Code of Practice for Concrete Road Bridges, New Delhi, India, 2011.

[6] Indian Roads Congress, IRC: 6 – Standard Specifications and Code of Practice for Road Bridges, Section II: Loads and Load Combinations, New Delhi, India, 2017.