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BRIDGING THE GAP: SUSTAINABLE EMERGENCY RESCUE AREA (ERA) DESIGN THROUGH DECK INTEGRATION

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Abstract

Emergency Rescue Areas (ERAs) are essential safety features in long viaducts, enabling emergency turnaround, breakdown management, and operational flexibility. In a dual carriageway marine viaduct comprising two independent single-cell PSC box girders, the conventional method of creating an ERA involves adding a median box girder to close the median gap. However, this approach presents multiple challenges, including the requirement for a new segment mold, additional foundations and substructure works, construction difficulties in a marine and intertidal environment, and significant disruption to Launching Girder (LG) erection sequences. These factors collectively increase project cost, construction duration, environmental impact, and safety risks. This paper presents an innovative engineering solution that eliminates the need for a median box girder by extending the cantilever decks of the adjacent PSC single cell box girders and integrating them through a 1-m-wide cast-in-situ longitudinal stitch joint. The design strategically retains the existing outer mold geometry, ensuring full utilization of the standard precast mold while avoiding the inefficiencies of fabricating a new mold for a small number of median segments. Structural continuity across the median is achieved using reinforcement dowels projecting from both box girders, while transverse prestressing within each precast segment enhances cantilever performance without relying on external struts – addressing quality, safety, and durability concerns associated with temporary supports in marine environments. Advanced finite element modelling, design optimization, and erection-sequence analysis were undertaken to validate the solution's performance under service and ultimate limit states. This innovation provides a cost-efficient, sustainable, and construction-friendly approach for ERA integration in marine viaducts, demonstrating the value of combining mold optimization, prestressed concrete engineering, and construction-driven design.

Keywords: emergency rescue area, PSC box girder, precast segmental construction, transverse prestressing, cantilever deck extension, mold optimization, sustainable bridge design

1 Introduction

Emergency Rescue Areas (ERAs) are vital safety features in long-span viaducts, enabling vehicle turnaround, breakdown management, and emergency response without disrupting traffic. Their importance is heightened in high-capacity corridors, where quick incident handling ensures safety and reliability. In dual carriageway viaducts with independent superstructures, ERA integration often demands structural continuity across the median. Conventional solutions add new structural elements, i.e. adding an additional box girder in between the main girders, but these increase complexity, cost, and environmental impact, especially in marine or intertidal zones where access, safety, and ecological constraints are severe.

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This paper proposes a construction-driven alternative that prioritizes efficiency, sustainability, and compatibility with segmental construction. By rethinking deck connectivity and optimizing prestressed concrete design, ERA functionality can be achieved without new structural lines or compromised constructability, offering a practical model for future road viaducts.

2 Background and conventional ERA practices

Dual-carriageway viaducts with independent superstructures (as shown in figure 1) are common in marine viaducts. However, Emergency Rescue Areas in these viaducts are typically formed by bridging the median gap using an additional deck element.

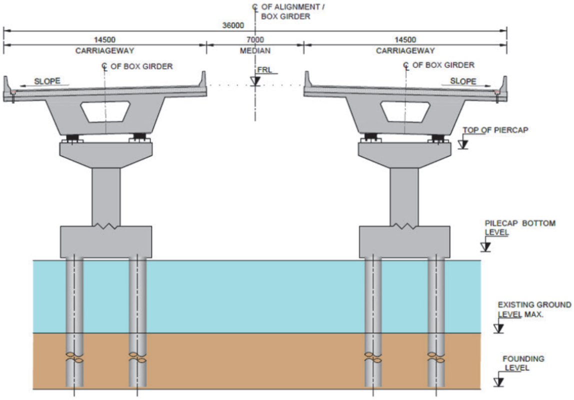

Figure 1 Typical Dual Carriage Way Viaduct with Independent superstructure

The most common practice involves introducing a central PSC box girder between the two carriageways, aligned longitudinally and supported by its own piers and foundations as shown in figure 2.

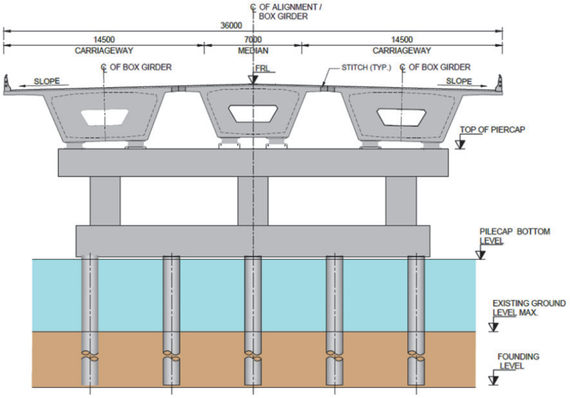

Figure 2 Emergency Rescue Area (Median Gap closure) with central median girder

This median girder provides the required deck continuity and load-carrying capacity for vehicular movement within the ERA. While effective from a structural standpoint, this conventional approach introduces several disadvantages when applied to marine viaducts. The median girder generally requires a unique cross-section and a dedicated precast mold (if precast), especially when its width differs from that of the main carriageway girders.

For projects where the number of ERA locations is limited, the cost and logistical effort associated with mold fabrication become disproportionately high. In addition, the introduction of a new girder necessitates additional substructure elements – piers, pier caps, and piles – constructed in environmentally sensitive marine zones. From a construction perspective, median girder erection disrupts the standard launching girder (LG) sequence. LG repositioning, alternating erection lines, and additional lifting cycles adversely affect productivity and progress of the project. Cast-in-situ alternatives, though eliminating the need for precast molds, require extensive temporary staging in marine/ intertidal zones, further elevating safety and environmental risks. These limitations prompted the search for a more efficient ERA integration strategy.

3 Concept development: deck integration strategy

To overcome the limitations of the conventional median girder approach, an alternative concept was developed based on deck integration rather than girder addition. The central idea was to extend the cantilever decks of the two adjacent PSC box girders and connect them structurally through a cast-in-situ longitudinal stitch joint as shown in figure 3.

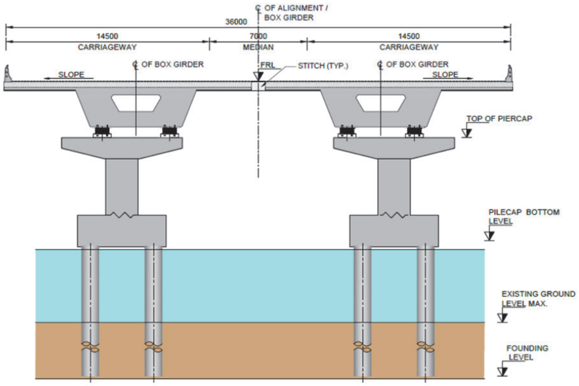

Figure 3 Emergency Rescue Area (Median Gap closure) with extended box girder

In this configuration, the ERA deck is formed by the combined action of the two extended cantilevers, eliminating the need for an independent median girder. Structural continuity across the median is achieved through reinforcement dowels projecting from each girder into the stitch joint, which is concreted after erection of both carriageways. This approach preserves the independence of the main girders during erection while enabling monolithic behavior in the completed structure. A key innovation of the concept lies in retaining the existing outer mold geometry of the standard 14.5 m wide PSC box girder. Instead of introducing a new cross-section, the required ERA deck width of 17.65 m is achieved by modifying only the cantilever arm lengths. This allowed full reuse of standard casting molds, significantly improving production efficiency and cost-effectiveness.

4 Structural arrangement

The superstructure of Emergency Rescue Area (ERA) is configured as a two-span continuous system, with each span measuring 34.95 m. The overall deck width of ERA is 36.3 m and it is achieved by integrating two independent single-cell prestressed concrete (PSC) box girders, each providing a deck width of 17.65 m, which are structurally connected through a 1.0 m wide longitudinal stitch joint to ensure continuity across the median.

The superstructure is supported on cantilever-type piers with independent pier caps carrying each carriageway, while each pier is supported by a group of four piles. The 3-dimensional perspective view of structural arrangement is shown in figure 4.

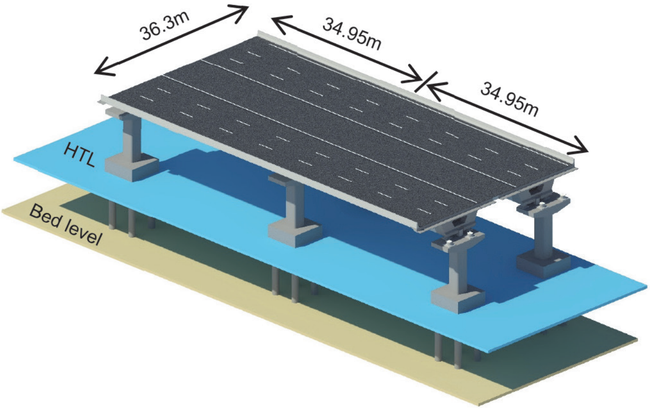

Figure 4 Structural Arrangement - 3D Perspective view of Emergency Rescue Area with extended box girder

5 Structural design methodology

The structural design of the Emergency Rescue Area (ERA) configuration was developed using a construction-oriented methodology that closely aligned with the actual erection sequence and anticipated service conditions. The design accounted for all critical actions, including dead and superimposed dead loads, vehicular live loads, braking and centrifugal forces, thermal effects, creep, shrinkage, and seismic demands. Special emphasis was placed on serviceability performance of the extended cantilever decks, crack control, and long-term durability in the marine environment. Transverse prestressing was adopted as a key design measure to enhance stiffness and limit deflections in the cantilever slabs of 5.08 m long, thereby eliminating reliance on external struts or temporary supports. The section checks for deck were designed using in-house spreadsheets. The detailed analysis for stress distribution zone is being analyzed by FEM using MIDAS civil software. For design of Pier and Pile, piles with soil springs along the depth are modelled in MIDAS software and soil structure interaction is carried out using FB Multipier software based on pier bottom forces from MIDAS software. The pile forces are obtained directly from the FB Multipier model and are used for SLS & ULS design. ADSEC software is used for section analysis of RCC members.

6 Finite element modelling and analysis

Finite element analysis of the ERA configuration was performed using MIDAS Civil, adopting a detailed global model that integrated both the superstructure and substructure. Three primary analysis stages were carried out for longitudinal model:

- stage-by-stage construction analysis reflects the actual sequence of segment erection
- service stage analysis for post-construction conditions under permanent and variable loads
- seismic analysis using the response spectrum method.

In longitudinal analysis model, both carriageways were idealized using beam elements, with the longitudinal stitch joint explicitly represented to capture interaction across the median.

The left and right PSC box girders were interconnected through transverse members extending between the respective webs at each nodal location. These transverse members were modelled as dummy beam elements providing stiffness only, enabling deformation compatibility and load sharing without introducing additional mass. All primary structural components, including the deck, piers, pier caps, pile caps, and pile foundation were modelled using beam elements. Figure 5 shows the Finite Element Model of Emergency Rescue Area in MIDAS civil.

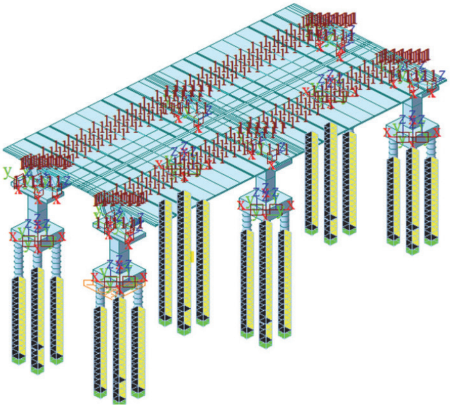

Figure 5 Finite Element Model of Emergency Rescue Area

Internal prestressing tendons were defined using global coordinates, allowing accurate representation of tendon profiles and force application. Figure 6 shows the tendon profile of single carriageway applied in MIDAS civil.

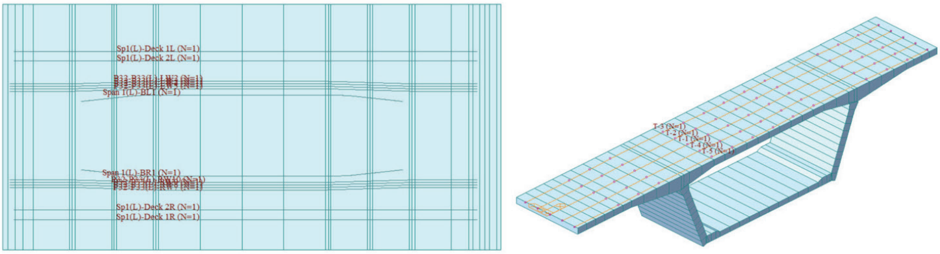

Figure 6 Tendon Profile of ERA

MIDAS Civil’s built-in functionalities were employed for automatic section property calculation, application of Indian traffic highway loadings, evaluation of creep and shrinkage effects, prestress loss calculations, construction stage simulation and stress checks.

A combined global model was adopted in which the superstructure and substructure were connected through elastic link elements to simulate bearing behavior. These elastic links were further connected to the adjoining structural components via rigid links, ensuring realistic force transfer and deformation compatibility. This modelling enabled the analytical model to closely replicate the actual structural behavior of the viaduct under construction, service, and seismic loading conditions. The transverse analysis of deck is carried out using beam and plate model to finalize the cross section of box girder. The 3-dimension cross section of middle segment is shown in figure 7.

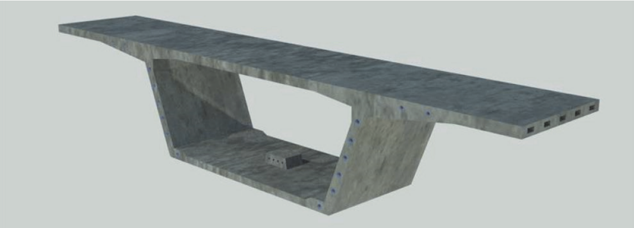

Figure 7 Cross section of Middle segment

7 Analysis and results

The stress and deflections checks were carried out in MIDAS civil software. The top and bottom stress values for SLS rare combination is shown in figures 8 and 9 respectively. The deflection value is shown in figure 10.

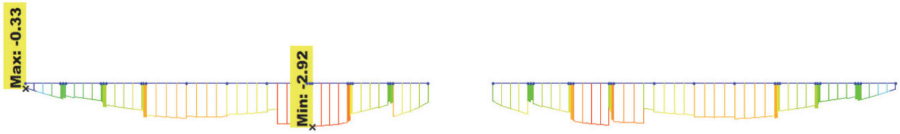

Figure 8 SLS rare combination – Top stress of girder

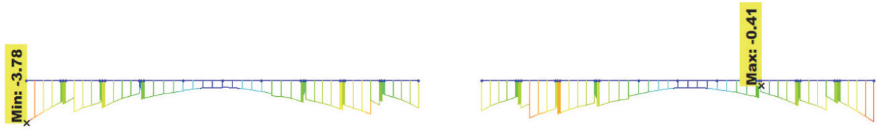

Figure 9 SLS rare combination – Bottom stress of girder

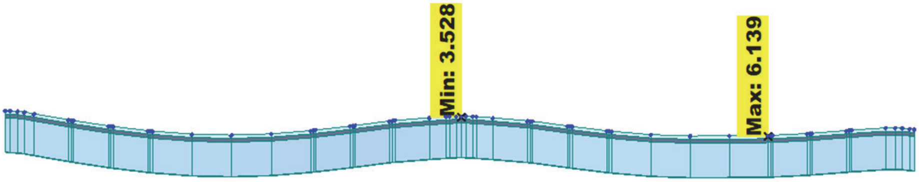

Figure 10 Deflection of girder under Live load

8 Construction methodology and erection sequencing

The construction methodology was developed in close coordination with erection logistics. All precast segments, including those with extended cantilevers, were erected using the same launching girder alignment as the typical viaduct. This avoided side-shifting of the LG and preserved uninterrupted span-by-span erection. After erection of both carriageways at ERA locations, the longitudinal stitch joint was cast in situ, connecting the two decks.

9 Sustainability and cost implications

The proposed solution delivered substantial sustainability and economic benefits. By eliminating the median girder and its substructure, significant quantities of concrete, reinforcement, and prestressing steel were saved. Per span material savings included approximately 70 m³ of concrete, 11.2 MT of reinforcement, and 2.8 MT of prestressing strands. The reuse of existing molds avoided capital expenditure associated with new mold fabrication and reduced production inefficiencies. Construction timelines improved by avoiding approximately 10 days per span otherwise required for median girder erection. Reduced LG movements and crane operations resulted in lower fuel consumption and an estimated CO_2 reduction of about 350 kg per m³ of concrete saved.

10 Discussion

Compared to conventional ERA solutions, the deck integration approach offers clear advantages in constructability, cost efficiency, and environmental performance. The solution demonstrates how structural optimization, when aligned with construction methodology, can unlock significant project-wide benefits. While the concept is particularly well-suited to marine viaducts, it is also applicable to urban and elevated corridors with similar geometric constraints. Limitations of the approach include dependency on cantilever capacity and LG lifting limits, which must be carefully assessed on a project-specific basis. Nevertheless, the methodology provides a robust and adaptable framework for ERA integration.

11 Conclusion

This paper presents an innovative and sustainable solution for integrating Emergency Rescue Areas in dual-carriageway marine viaducts. By extending and integrating the decks of adjacent PSC box girders through a longitudinal stitch joint, the need for a conventional median box girder is eliminated. The solution achieves structural performance, construction efficiency, cost savings, and environmental benefits simultaneously. It establishes a replicable benchmark for future marine and urban viaduct projects, demonstrating the value of combining prestressed concrete engineering, mold optimization, and construction-driven design.

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