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Innovative Solutions for Bridge Construction: The Role of Closure Pour and Diaphragms in Accelerated Bridge Construction (ABC)

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I. Introduction

Bridges have been an integral part of our societal infrastructure, playing a crucial role in daily commutes. In the realm of transportation engineering, researchers and engineers have continuously advanced various technologies and construction methods to achieve more cost-effective, secure, and convenient project outcomes. Consequently, the adoption of Accelerated Bridge Construction (ABC), a method that saves time, emerges as an optimal approach for bridge replacement/rehabilitation. The Accelerated Bridge Construction method represents one of the latest innovations in construction techniques. Prefabricating bridge elements not only yields notable time and cost reductions but also provides safety and convenience benefits for travelers. The utilization of prefabricated bridge elements addresses multiple construction challenges, contributing to improved overall efficiency. Over the past decade, the construction industry has increasingly embraced ABC, recognizing its potential benefits. This innovative construction technique offers advantages such as reduced construction time, lower accident rates, and enhanced safety when executed correctly.

In major bridge and flyover projects, the incorporation of Accelerated Bridge Construction (ABC) techniques, which encompass the utilization of new materials, design processes, construction procedures, high-strength materials, and updated management methods, is imperative. The current demand calls for the implementation of ABC to expedite these projects, allowing for completion within significantly shorter timeframes. ABC technology relies on inventive planning, incorporating advanced designs, materials, and construction methods that ensure safety and cost-effectiveness, ultimately reducing on-site construction time. The utilization of high-performance concrete (both reinforced and prestressed), high-strength steel, and innovative joints becomes instrumental in accelerating the overall speed of construction.

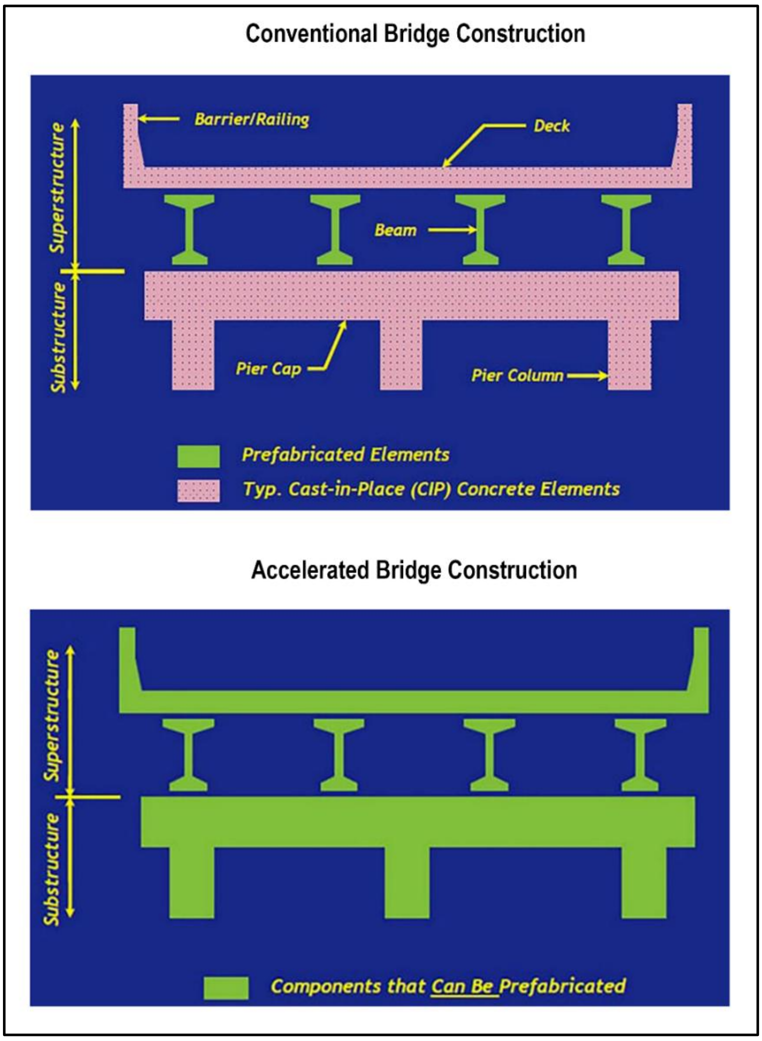
Precast components for culverts and bridges are globally employed to expedite the execution of culvert and bridge projects. These components are manufactured in a controlled factory environment and subsequently transported to the construction site. To facilitate this process, it is crucial to create comprehensive construction drawings for precast culverts and bridge components, encompassing various span lengths and widths. These drawings must undergo approval from competent authorities to ensure their suitability for project implementation. In India, the necessary machinery for transporting precast box culverts and bridge components is now readily available. After completion of offsite manufacturing, the prefabricated elements are transported to the construction site and meticulously assembled. This process involves closure pours that utilize high-performance materials to ensure structural integrity. Furthermore, diaphragms are frequently utilized to bolster connections between specific prefabricated components, such as beam elements. The present research study is dedicated to analyzing the innovative approach of Accelerated Bridge Construction with Closure Joints at Pier Diaphragms, aiming to enhance understanding and implementation of this method for efficient and durable bridge construction.

II. Accelerated Bridge Construction

Accelerated Bridge Construction plays a pivotal role in improving site constructability, project timelines, and travel safety within the work zone. ABC effectively mitigates the impact of heavy traffic, shortens on-site construction duration, and minimizes delays caused by adverse weather conditions.

Figure 1

Conventional and Accelerated Bridge Construction



An indispensable factor contributing to the success of Accelerated Bridge Construction (ABC) lies in its strategic integration of prefabricated bridge elements. This innovative approach eliminates the cast-in-place construction phase from the critical path of the project, enabling it to take place offsite in a controlled environment. Prefabrication offers the advantage of concurrently manufacturing components near the bridge alignment while other construction tasks are underway. This concurrent activity streamlines the overall construction process, facilitating faster progress compared to conventional methods. As a result, field construction is expedited, saving valuable time and resources. Overall, the integration of prefabricated components not only accelerates construction but also contributes to cost-effectiveness, making it a highly beneficial approach for bridge projects.

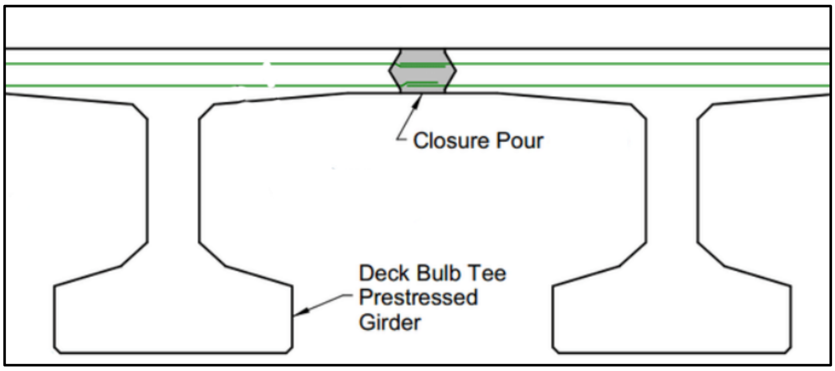
Generally, ABC involves on-site or off-site precast elements for bridges, which are transported to the bridge location and installed in situ. These prefabricated elements are then interconnected through casting-in-place connections to form a continuous structure. Closure joints, commonly referred to as deck joints, play a crucial role in this process. The efficiency of these joints, intended to quickly become operational, relies on factors such as concrete mix design, reinforcement and encasing details, as well as the placement and curing procedures. Closure joints in ABC typically incorporate reinforcing bars and encasements of various shapes, which may lead to congestion within the joints under certain circumstances. Although closure joints are anticipated to provide quick functionality because of their cast-in-place nature, worries remain regarding the possibility of defects. This raises apprehensions about the likelihood of defects remaining in the joints, increasing the risk of exposure and other degrading effects over time. Consequently, there is a potential reduction in both the joint's and the overall structure's strength and serviceability.

III. Closure joints for ABC

Commonly, closure joints pertain to the links between the bridge deck components and the substructure. Implementing Accelerated Bridge Construction (ABC) with prefabricated elements and assemblies necessitates connections for joining and integrating the bridge structure. Various types of ABC connections have been examined through experimental and analytical means to assess their viability.

Figure 2

Closure Pour Connection



The objective of closure pour connections is to ensure continuity in the deck and effective force transmission between neighboring units. Incorporating diaphragms reinforces the connection and enhances stability. Engineers perform live load analysis featuring closure pours and diaphragms by employing distribution factors outlined in IRC:SP LRFD (Indian Roads Congress Bridges Specifications and Standard Committee Load and Resistance Factor Design). These factors assume the structure behaves as a monolith. LRFD distribution factors simplify the load analysis process for engineers, allowing them to assess the effects of live loads on individual girders without the need for intricate 3D analyses. By employing recommended code equations, designers can allocate a portion of the live load moment generated by one or more lanes of load to individual girders.

To devise the code equations, finite element analysis (FEA) served as a precise technique for assessing the outcomes derived from IRCBSS LRFD equations. Various bridge models underwent analysis considering critical parameters affecting bridge response to live loads, such as length of the span, girder spacing, and slab thickness. The finite element analysis (FEA) presumed continuous slabs in the lateral direction., thereby removing potential interference in transverse load distribution caused by closure pour joints in bridge decks. However, these models did not account for the influence of diaphragms.

IRC allows for the design of bridges featuring longitudinal closure pour joints and diaphragms using LRFD distribution factors, provided proper connectivity exists. However, limited research has explored the impact of longitudinal joints, particularly concrete joints, on live load distribution in such bridges. Closure pours are intended to facilitate adequate load transfer between prefabricated components, allowing engineers to analyze the structure under the assumption of a continuous deck. However, due to the lack of attention given to studying the effect of these joints on load distribution, the structure may be vulnerable to damage. Hence, it has become imperative to investigate the behavior of concrete bridges with concrete closure pour joints.

IV. Diaphragms

Diaphragms serve the purpose of resisting lateral forces and transmitting loads to the supports. While some diaphragms are post-tensioned, others are reinforced with conventional materials. They are essential for providing lateral stability during construction and for resisting and transmitting seismic loads. Previous studies suggest that diaphragms are not effective in preventing deflections or reducing member stresses. Furthermore, there is widespread acknowledgment of the significant role diaphragms play in the overall distribution of active loads in bridges.

Figure 3

Diaphragms

Placing of Diaphragms in the site

The primary function of diaphragms is to provide a stiffening effect to the deck slab in the event that bridge webs are not precisely positioned on top of bearings.

Figure 4

Positioning of the Diaphragms

Diaphragm on a concrete girder

Diagphragm intermittently in between supports in the midspans

Diaphragm diagnol

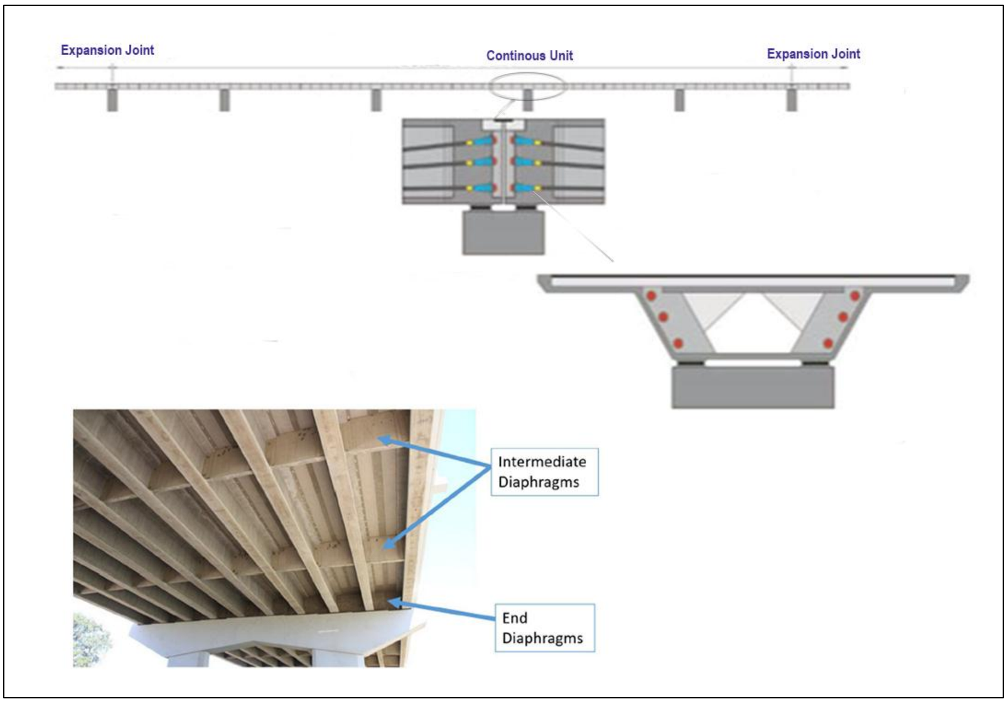
Diaphragm on the site

If bridge bearings are situated directly beneath the webs, diaphragms might not be necessary since loads in bridge decks can be directly transmitted to the bearings. However, diaphragms play a crucial role in improving the load-sharing characteristics of bridges. Specifically, they provide torsional restraint for the bridge superstructure. A standard concrete closure pour connection comprises steel reinforcing rods and a high-strength concrete mixture to form the connection. The reinforcing bars found in the connection are the transverse reinforcements protruding from the adjacent bridge components. The alignment of the bridge components is dictated by the overlap length and spacing of the reinforcing bars in the connection. Once the components are accurately positioned, the concrete mixture is poured into the joint.

While there has been limited research focusing on the effects of closure pour joints, the impact of diaphragms has been extensively studied since the 1960s. Despite numerous papers published on the efficacy of diaphragms, the role of intermediate diaphragms remains a subject of controversy. IRC categorizes diaphragms as either end diaphragms or intermediate diaphragms. Figure 5 illustrates the use of end diaphragms (EDs) over supports and intermediate diaphragms (IDs) within the span. End diaphragms are frequently utilized in bridge construction and are celebrated for their ability to improve the load-sharing dynamics of bridges. However, the significance of intermediate diaphragms in enhancing bridge performance and the reasons behind their incorporation exhibit variations across different states and regions. While end diaphragms are widely acknowledged for their structural benefits, the rationale for incorporating intermediate diaphragms remains subject to differing interpretations and design practices.

Figure 5

Intermediate and end diaphragms in a concrete bridge



The utilization of intermediate diaphragms (IDs) offers benefits such as connecting bridge girders to prevent accidental overturning during construction. Research indicates that well-designed IDs can also improve lateral and vertical load distribution. However, conflicting conclusions exist regarding the effectiveness of IDs in live load distribution. Some studies suggest that IDs can increase the susceptibility of girders to damage from impacts by overheight trucks, transmitting damage laterally to other girders. Additionally, certain research indicates that IDs may not consistently reduce the maximum moment in girders and can sometimes lead to an increase. Due to the controversy surrounding the efficacy of IDs, the models used to validate distribution factor equations often neglect diaphragm effects. Incorporating diaphragm effects into simplified formulations is challenging due to variations in number, type, spacing, and layout across bridge systems. Modeling concrete diaphragms requires consideration of composite and non-composite action, variation in rigidity due to diaphragm cracking, and diaphragm-girder connections. Limited research data provide recommendations for modeling concrete diaphragm stiffness and connections, contributing to discrepancies in study results.

Cost is a significant factor influenced by the intermediate diaphrams. Some studies indicate that adding IDs to precast girder bridges incurs unnecessary costs, as bridges without IDs still meet code design requirements for displacements and stresses. Recommendations include increasing prestressing strands in prestressed concrete girders instead of using IDs to save costs. Despite these findings, many concrete bridge designs continue to incorporate IDs. Consequently, this thesis also examines the impact of closure pour connections in precast concrete bridges and evaluates the role of IDs.

V. Summary

The utilization of Accelerated Bridge Construction (ABC) offers significant advantages in mitigating the impacts of on-site construction activities on the flow of the transportation network and the overall safety of road users. One of the most notable benefits of ABC is its capacity to minimize mobility impacts, or ideally, maintain uninterrupted traffic flow. On-site construction activities have been closely linked to substantial social ramifications concerning safety and mobility. In certain scenarios, the direct and indirect costs associated with traffic diversions resulting from the closure of a bridge during construction can surpass the cost of the structure itself. Moreover, ABC presents several other compelling reasons, including considerations of site constructability. Typically, the ABC approach offers solutions that are more cost-effective and practical in comparison to conventional construction methods. These traditional methods often necessitate the expensive deployment of temporary structures, lengthy detours, extended construction durations, and reliance on remote construction sites.

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