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ACCELERATED BRIDGE CONSTRUCTION AND ITS RECENT TREND

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ABSTRACT

Accelerated bridge construction is a relatively new method of construction but has gained popularity in recent decades among the bridge engineering community due to its notable advantages over conventional construction methods including fast project delivery, reduced traffic impairment and construction hazards, and increased quality and cost-effectiveness. Continuous efforts in research by academia and construction industry have allowed the accelerated bridge construction to be implemented for almost any part of a bridge in different ways. While it appears that a strong ground has been made, there are still areas to improve upon such as its use in seismic areas. This paper presents some of key accelerated bridge construction technologies and their benefits, limitations as well as recent trends.

Keywords*: bridge, accelerated construction, replacement, superstructure.*

1. INTRODUCTION

The increasing need for bridge renewal and replacement in the United States has grown exponentially in the past decades. Yet, municipalities and State Departments of Transportation (DOTs) seem to fall short of meeting this growing need due to the rising cost of bridge repair/replacement coupled with other issues that arise during the construction. According to a report [1] by the American Society of Civil Engineer (ASCE), the bridges in the United States have an overall grade of C+ indicating that substantial portion of the nation's bridges is in poor conditions and functionality. Based on this grade, it is evident that these problematic bridges need to be repaired or replaced in the coming years. Conventional cast-in-place construction methods generally require reduced traffic lanes or relocation of traffic on detour, use of temporary bridge and bypass roadway and/or staged construction for extended period of time to maintain the flow of traffic. Traffic detours often result in increase in traffic congestion and the use of temporary structures and/or staged construction often take up large part of the available budget and are sometimes not practically feasible. In addition, long onsite construction may cause driver distraction raising safety concerns of the construction workers and the traveling public passing the work zone. A promising solution to offsetting some of the costs and other issues associated with bridge repair/replacement is accelerated bridge construction (ABC).

Whether it be the first precast segmental bridge built in France in 1960s, or a fully precast network arch bridge recently completed in Texas, accelerated construction practices have been widely adopted throughout the US and the world. Traditionally, concrete bridges have been limited to cost effective use in shorter spans while

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steel bridges have been more frequently used for long spans. However, the introduction of segmental precast bridges created opportunity for intermediate and long-span concrete bridges that, in many instances, have proven to be cost effective over steel bridges [2]. One of the major advantages of using segmental bridge construction with precast segments is the ability to fabricate structural elements during other construction periods that allows reduced total construction time. Another benefit over the cast in place construction is that since the prefabricated segment has already cast and fully cured, the effects of shrinkage due to moisture loss during curing or creep effects are largely mitigated. Other notable benefit includes the ability to remove the need for false work in the erection. One example is the balanced cantilever construction method, a method in which segments of the bridge are cantilevered off of the piers sequentially to balance themselves on the pier and eventually meet up the cantilevered sections at the abutments. As the precast segments are supported by the finished piers or structure, this method allows for the elimination of false work, erection time of false work, and the potential dangers associated with potential false work failures, regulations, or site difficulties [2].

2. ACCELERATED BRIDGE CONSTRUCTION

ABC is known as a design and construction technique intended for rapid construction of bridges by using prefabricated structural elements. According to the Federal Highway Administration (FHWA), "*ABC is bridge construction that uses innovative planning, design, materials, and construction methods in a safe and cost effective manner to reduce the onsite construction time that occurs when building new bridges or replacing and rehabilitating existing bridges*" [3]. Typical examples (Fig. 1) of ABC technologies in bridge construction are the use of prefabricated/precast members that allow for decks, beams/girders, pier caps, foundation elements, abutments, and even entire superstructure systems to be completed prior to construction, and brought to site and installed in a modular fashion, substantially reducing construction time, cost, safety issues, and minimizing traffic interruptions.

(a) Placement of a pier cap [4] (b) Placement of a superstructure module, courtesy of JMT [5]

Figure 1 – Placement of prefabricated structural element or module.

In the early years of developing ABC, the research focused primarily on decks and pier caps and it was still a big stride for being able to implement ABC. In recent decades, research efforts and advancement in technology have allowed for ABC to become an even more attractive method for constructing bridges and, nowadays, the research and effort to implement ABC technologies have progressed to footings, substructures as well as their use in seismic areas. Numerous engineers and bridge owners believe that ABC would provide a way for bridges to be repaired/built in a timely manner without extended disruption of traffic that conventional construction may cause, while providing cost saving benefits. ABC can be used not only for new bridge construction, but also rehabilitation or replacement of existing bridges. Some say that ABC is most effective in situations where a bridge needs to be repaired or replaced [3] because the speed in which ABC allows for the construction to be completed helps reduce the impact that construction has on the traffic.

There are numerous benefits to using ABC such as lowering the impacts of construction on traffic and reducing the amount of construction time on site [3]. Since ABC uses prefabricated structural elements, the amount of time that the bridge itself or surrounding roads must be closed can be decreased dramatically. By reducing the time of construction, workers and motorists have a reduced exposure time to the potential risk of an accident. In addition, since the prefabricated elements are often made in a plant, the safety of construction workers is improved by reducing the amount of labor that construction workers have to face at the construction site [3]. In the plant, the conditions are typically much safer to work in as there is no traffic moving close by [6]. Also, prefabricated members made in plants are not exposed to the differing environmental conditions until after they are made and brought to the bridge site. The cost benefit of using ABC is not as obvious as some of the previously mentioned benefits. In fact, the initial cost of ABC can be anywhere from 20% to 30% higher than that of conventional bridge construction. This percentage depends on the complexity and size of the bridge, time restraints, and need for specialized equipment to complete the project [3]. Recent cost analyses, however, have shown that the long-term benefits of ABC outweigh the overall costs when compared to that of conventional construction methods. Moreover, when the cost to society is added to these analyses, it becomes even more obvious that ABC is much efficient [7]. This is due to the shortened time period that traffic delays are caused by construction. For example, construction zones are likely to cause a negative economical impact on commercial and industrial businesses in the area when traffic lanes are reduced or traffic is rerouted. This means that utilizing ABC would minimize unnecessary risks that businesses and traveling public may take during construction [7].

3. ACCELERATED BRIDGE CONSTRUCTION TECHNOLOGIES

‘Prefabricated Bridge Elements and System’ (PBES) is the most common practice in ABC in which the structural elements of a bridge, such as prefabricated concrete slabs and box beams, and prestressed I-beams [8], are built off-site, commonly in a plant near the job site, and then shipped to the construction site to be assembled [3]. This method can be used for new bridge construction as well as for replacement of older bridges. To date, advancement in technology and fabrication processes allow for practically any component of a bridge to be prefabricated while the most common part of the bridge to be prefabricated is superstructure and deck elements. This is because these components can easily be duplicated due to their redundant nature in design [8]. For example, there may be six identical girders in a bridge that can all be made based off the same mold, which helps lower the costs of prefabrication. The joints between the prefabricated elements, however, often require additional considerations in terms of their durability and structural integrity and, thus, techniques such as high strength grout, pre- and post-tensioning are often used at these joints. A report by American Concrete Institute (ACI) recommends that certain methods of connecting prefabricated elements be utilized with precast connections [9].

Another key ABC technology that can be used for foundations of bridges to be constructed in an accelerated way is the 'Geosynthetic Reinforced Soil Integrated Bridge System' (GRS-IBS). This method is used to create an integration of foundation, abutment and approach embankment and make all the components act as a composite unit. A typical GRS-IBS consists of three main parts: a reinforced soil foundation (RSF), a geosynthetic reinforced soil (GRS) abutment, and an integrated approach [3]. The base of the GRS-IBS is the RSF, which is mostly compacted granular fill surrounded by geotextile fabrics. The main purpose of RSF is to keep water from filtering into the abutment and provide a larger bearing area for the abutment. On top of this base foundation, the GRS abutment is constructed. This part of the GRS-IBS is built by layering geosynthetic reinforcement and compacted soil. The interaction between the two materials improves the strength and stiffness of the soil [10]. The bridge is then placed directly on the abutment and the integrated approach is placed on the GRS abutment leading up to the bridge. One of the benefits of using the GRS-IBS would be a shortened construction time as it does not require the excessive excavation that is typically needed for deep foundations [11]. Also, since the three components of the GRS-IBS are integrated and act as a composite unit, it would eliminate the potential 'bump' at the joint that might occur due to a different settlement between the bridge and the approach slab, thereby providing a smooth ride to the traveling public. In addition, it is estimated that the cost of a bridge project can be reduced by 25 to 60% if the GRS-IBS is used.

In a typical ABC site, conventional equipment such as cranes, strand jacks and climbing jacks are often used to lift and place the prefabricated elements. A gantry crane system is also frequently used in ABC due to its capability to rapidly move structural elements to various location of a bridge once properly installed. In a situation where a large prefabricated structural element or a module of a bridge needs to be transported to the bridge site, 'Self Propelled Modular Transporters' (SPMTs) can be utilized (Fig. 2). SPMTs are the highly maneuverable transport trailers that can connect extra trailers longitudinally and transversely to form a large transport equipment. A typical SPMT can carry approximately 50,000 pounds per axle line while some can carry over 75,000 per axle line [3].When a bridge construction takes place in environmentally sensitive areas, a 'longitudinal launching' method can be used. In this method, a superstructure or a module is prepared in the launching pit in one or both ends of the abutment depending upon the span length of the bridge. It is then jacked longitudinally out, incrementally over the span using roller or sliding system. Another rapid construction method, other than the ‘launching’ method, that is gaining numerous attention in the recent past is the ‘Slide-in bridge construction’ (SIBC). In SIBC (Fig. 3), a new bridge is built off site on temporary support frames and rails, and then slid into place and tied to the existing approaches. This method is also known as the ‘lateral slide’ as the bridge is built parallel to the existing bridge or to the future location of the bridge and then ‘laterally’ slid into place [3]. The SBIC method helps minimize the road closure time periods because the roadway could remain open until the demolition of the existing bridge and the placement of the new bridge by ‘sliding’ take place. This process could take as little as 72 hours [3] substantially reducing the impact to traffic.

Figure 2 - Superstructure module transported by SPMT, courtesy of CoPlant, Ltd [12].

Figure 3 - Simulated superstructure placement by SIBC, photo courtesy of Garver, LLC [13].

4. SEISMIC CONSIDERATIONS IN ACCELERATED BRIDGE CONSTRUCTION

While ABC technologies are being widely adopted throughout the world, the use of ABC in moderate to high seismic areas has been somewhat limited because of the seismic forces that the bridges in those areas need to be designed for. During the seismic activity, it is important that adequate continuity be present between the precast

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elements so that adequate elastic behavior of the superstructure is maintained. Also, column-to-footing and column-to-pier cap connections should develop plastic hinges during extreme events such that the seismic forces be adequately dissipated to prevent brittle failure. The main challenge for designing bridges using ABC in seismic areas is that the beam-to-column and column-to-foundation connections be designed such that they are strong enough to withstand the transverse seismic forces that cause large inelastic cyclic deformations, moments and shears [14]. Numerous researches have been conducted to investigate and develop the connection typesthat would allow ABC to be used in seismic areas. An example of such connection types is “emulative” connectors that are intended for precast concrete bridge columns. These connections are categorized as ‘emulative’ because of their ability to emulate the performance of typical cast in place connectors [15]. An ‘emulative’ connector is basically a socket connection that is developed primarily for column-to-footing connections. With this connection type, a column-to-footing connection can be made by placing precast columns in a ‘socket’ of a footing followed by applying grout to the connection to hold the column in place. In the socket connection, the grout used between the column and footing is where the strength of the connection comes from. Often the edges of the column and footing at the connection is roughed to allow more surface area for the grout to bind to [16]. Laboratory testing [15] of the socket connection revealed that adequate performance of the connection under constant vertical and cyclic lateral loading was achieved. A similar type, a grouted duct connection, can be used for both column-to-footing and column-to-cap connections. In this connection, the footing or cap beams have steel ducts in them and the reinforcement from the columns are placed and grouted in the individual ducts. The performance of these ducts depends on the embedment depth of the reinforcement, the diameter of the ducts, and the compressive strength of the grout [14]. The connection design for high seismic areas typically requires that the reinforcement bar diameter be much larger than that of non-seismic design. This poses a problem of needing longer development lengths that are not often feasible to attain with the cap beam or footing. A recent research [14] on the grouted duct connections through pullout and cyclic loading tests, however, indicated that the development length can be reduced when they are grouted in the steel ducts. A study by Ameli and Pantelides [15] has also shown that these connections have adequate ductility in terms of strength and displacement when compared to typical reinforced concrete connections. Shown in Figs. 4 and 5 are examples of column-to-footing and column-to-cap beam connection details [16].

Vander et. al. [17] investigated an integral system with I-shaped girder and inverted tee cap connection under lateral seismic and cyclic vertical loads. The connection consisted of grouted, unstressed post-tensioning strand connecting each of girder to peir cap [17]. A study by Tazarv [18] proposed a column-to-footing connection detail (shown in Fig. 6) that consists of ultra-high performance concrete (UHPC) grout and Nickel-Titanium shape memory alloy (SMA) longitudinal reinforcement and engineered cementitious composite (ECC). Headed bar couplers were used to connect SMA to steel bars while grout couplers were used in column-to-footing connection. The experimental results showed that the UHPC filled ducts were not damaged under 12% drift ratio cycles and that the SMA longitudinal reinforcement provided adequate base shear and displacement capacities.

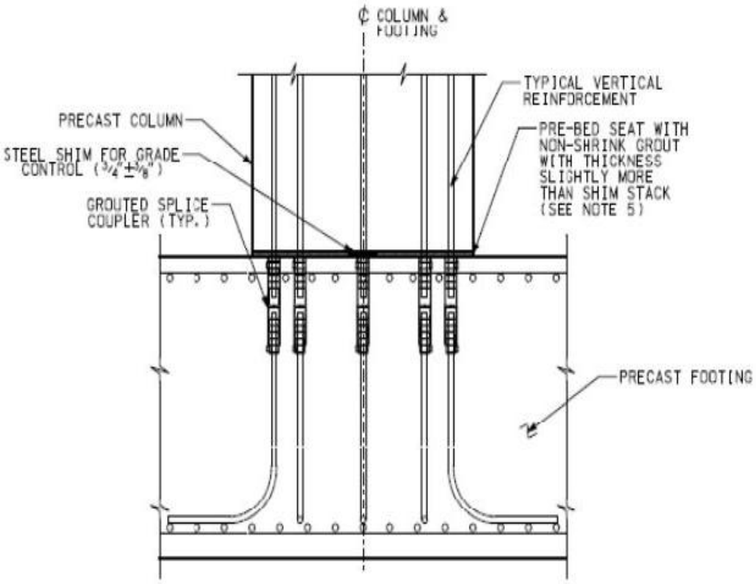

Figure 4 – Bar coupler column-to-footing connection detail, courtesy of NCHRP [16].

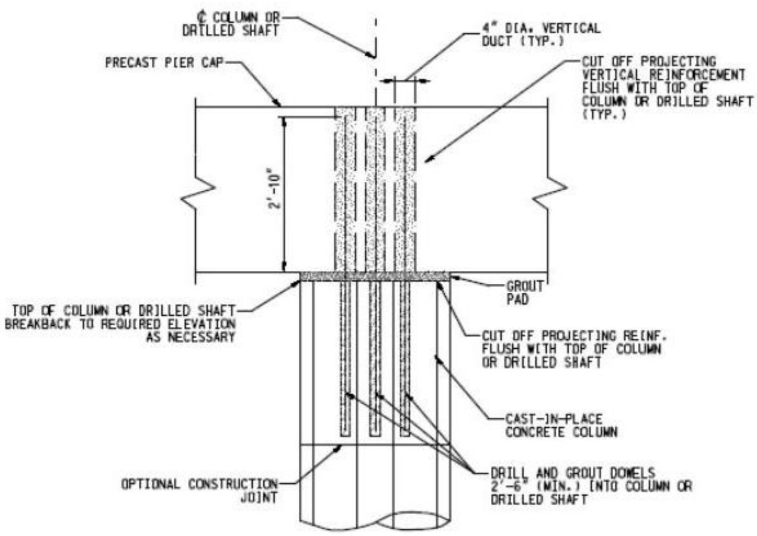

Figure 5 – Grouted duck connection detail, courtesy of NCHRP [16].

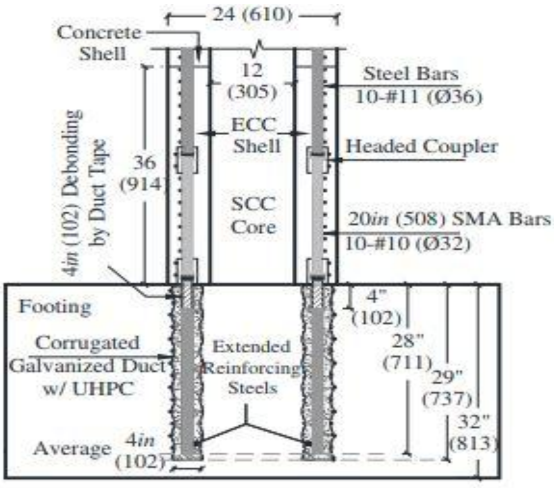

Figure 6 – Base connection detail for precast column in seismic area [18].

5. CONCLUDING REMARKS

Overall, accelerated bridge construction appears to be an effective and efficient alternative to the conventional bridge construction methods. Although ABC is still a relatively new method of construction, there are already well known benefits to using ABC. The reduced amount of construction time on-site (or simply rapid construction) leads to the benefits of having shortened traffic delays due to the construction and also decreases the environmental impact that traffic jams may cause. Although the current initial cost of using ABC still may be more than that of the conventional construction, it has a high cost-benefit ratio in the long term. With increased quality of the structural elements, one can expect a longer service life of the bridge, which will reduce repair and rehabilitation costs down the line. Also, as ABC is used more often, it is likely that the practices will become more standard and that the initial cost of ABC will go down. While the future of certain ABC technologies such as GRS-IBS, PBES, and SIBC seem promising, there is still work to be done on how to best implement those methods. Careful consideration on how ABC could be utilized at a specific site should be taken during the design and planning stage because the benefits and savings are often directly related to construction fluidity, material and labor costs, and environmental, economic, and traffic impacts. As continuous research efforts are taken in the areas of connections, seismic and other design elements, it is envisioned that ABC will be used more widely and for more complex projects.

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