HISTORY OF ACCELERATED BRIDGE CONSTRUCTION AT BergerABAM

James S. Guarre, PE, SE, BergerABAM, Irvine, CA
M. Lee Marsh, PE, PhD, BergerABAM, Federal Way, WA
Robert F. Mast, SE, BergerABAM, Federal Way, WA
Greg A. Banks, PE BergerABAM, Federal Way, WA

ABSTRACT

Accelerated Bridge Construction (ABC) methods have been used by BergerABAM for more than 50 years. The key success factor on ABC projects is using the optimal blend of precast concrete and cast-in-situ concrete components on bridge-type projects. ABC techniques began in the early 1960s with the development initially used to span up 120 feet. Use of precast concrete bridge girders accelerated bridge superstructure construction. Subsequently, ABC methods were used on transit/people-mover projects and bridges in Disney World; Vancouver, BC; Getty Center in Los Angeles; and the Reedy Creek Bridge in Orlando. BergerABAM was selected to lead a Highways for LIFE Technology Partnerships project in coordination with Washington State Department of Transportation and the University of Washington to develop precast concrete bent substructures in high seismic zones. These techniques were used on a prototype bridge over Interstate5 and on a bridge project spanning across State Route 520. This paper will present a collage of seven bridge/transit projects to demonstrate the increasing use of precast concrete components over 50 years to shorten on-site construction time.

Keywords: Accelerated Bridge Construction, Precast Bridges, History, Bridges

INTRODUCTION

Accelerated Bridge Construction (ABC) is a watchword for the bridge engineering profession today. Most bridges being built present challenging conditions of site constraints, construction windows, and maintenance of traffic. Thus, a myriad of techniques are being used to accelerate construction, and these may include precast bridge elements and systems (PBES) or specialized techniques to move large pieces of the bridge, such as entire spans. The focus of this paper is to chronicle selected elements of BergerABAM's history of using what today is called ABC. The purpose of this chronicle is to illustrate that the bridge engineering community has been innovating along the lines of ABC for many years, and today, what is different is the quest for accelerating construction has more structure and visibility to it. We now have a name for it; it is called ABC.

This paper will briefly look at several case histories of ABC, from the early days of prestress in the United States, to the 1950s, and progressing to the current millennia. The work of BergerABAM is featured herein, but this paper is not about the firm, so much as it is about the process, evolution, and thinking that went into the work. All of these case histories involve concrete structures. A theme of this synopsis is that synergy between designer and constructor can result in a unique mix of precast, prestressed, and cast-in-place (CIP) elements that elegantly solve both constructability and structural challenges. This mix is difficult to standardize and instead must evolve uniquely for each project, addressing specific challenges of that particular application. A "tool box" of solutions, however, is certainly a useful concept, and history proves that those solutions can be used differently, but effectively, for a myriad of applications. This is one of the most important facets of understanding and applying ABC techniques.

THE EARLY YEARS

In 1951, Art and Tom Anderson cofounded the Concrete Engineering Company, which became Concrete Technology Corporation (CTC), and is still going strong today. The company was founded to manufacture precast, prestressed concrete products[1]. Because this material was not covered in the building and bridge codes of the day, building officials were often resistant to permitting use of the novel material. Consequently, the Andersons set about constructing their own manufacturing plant of the material to demonstrate its effectiveness, and they often put on load demonstrations of their products (Fig. 1). The brothers also started an engineering company with Hal Birkeland and named it Anderson, Birkeland, and Anderson, which then after Bob Mast joined, became ABAM[2]. The engineering company pursued many types of work but often used precast, prestressed concrete when it made sense. From these beginnings, ABAM developed an effective collaborative attitude and relationship with the construction industry. These engineers developed a penchant for combining precast with conventional construction to facilitate effective and often faster construction, a technique today known in the bridge industry as ABC.

Others in the country were working in this same area, and from those early pioneers, today's precast, prestressed concrete industry grew. From those early efforts, the material began to be used widely from buildings to bridges to marine structures to just about any structure that one could imagine. Unique structural shapes were developed to be as efficient as possible. An example is the bulb-tee girder shape; also, it was quickly realized that the diaphragms, curbs, and other appurtenances for simple bridges built of these beams could be integrated at the plant to avoid doing the work in the field (Fig. 2), comprising an early ABC feature. This began the mixed and judicial combination of precast and CIP components—later to become known as PBES. As the industry grew, one of the new markets in the Pacific Northwest was the logging industry.

Some of the first BergerABAM ABC projects were completed for the logging industry in Washington State. There was a rising synergy leading to this. Logging bridges were often built of several timbers—actual logs, in the 5-foot-diameter range—lashed together with dirt placed on top to form a temporary bridge. However, these did not last very long and the wood in the timbers was worth more than concrete beams. At the same time, the precast, prestressed concrete industry was in its infancy and looking for projects to showcase the products being developed. The combination of the logging industry and precast concrete industry was a natural collaboration.

Fig. 1 Art Anderson, "Let's Ask the Beam" —a test evaluating how an I-beam behaves with large openings for utilities in a high-rise office building.

Fig. 2 Early Deck-Bulb Tee Being Placed in Washington State

SOLLECKS RIVER BRIDGE

ABAM's work on logging road bridges culminated in the design and construction of the Sollecks River Bridge on Washington's Olympic Peninsula in 1967. The bridge spans a 230-foot-wide canyon and was designed to provide access for 75-ton logging trucks. A unique requirement was that there was only heavy equipment access from one side of the canyon as there were as yet no roads on the other side. Thus, a unique design was developed comprising precast bridge girders combined with precast beam-column struts to both limit the main span to beam sizes that could be trucked on logging roads to one side of the bridge site and to minimize the amount of on-site construction work needed for the bridge abutment construction on the steep canyon side slopes.

Working with the construction contractor, ABAM adapted its bridge element design so that the precast, prestressed concrete beams and precast, prestressed concrete beam column struts could be lifted from the delivery trucks and moved into their final position on either side of the canyon using a 1,200-foot-long high line overhead cable system (Fig. 3). This cable system was anchored to the hillsides on either side of the canyon above the bridge site. This unique adaptation of logging industry technology, typically used to move large cut trees to a landing (central point in a logging area for loading), was thus combined with off-site precasting to make construction of a bridge at this difficult site economically feasible. This bridge is still in service along a U.S. Forest Service road.

Fig. 3 Sollecks River Bridge Erection

SCATTER CREEK BRIDGE

Another logging industry, rapidly constructed precast bridge was the replacement of Weyerhaeuser's Scatter Creek Bridge near their mill on Highway 410 near Enumclaw, Washington (Fig. 4). A flood had washed out both the adjacent state highway bridge and the logging road at this location. The logging road to the Weyerhaeuser's mill paralleled the highway to permit passage of trucks three times heavier than the highway legal load. The logging bridge was designed, fabricated, erected and put into service just two months after the flood, while the highway bridge took two years to replace.

The structure comprised precast girders, precast columns (which were attached with pins to the girders and rotated into place during erection), precast back struts to the abutments, and CIP abutments. Sadly, with the closure and then removal of the Weyerhaeuser mill, which the road served, the bridge was taken down.

Fig. 4 Scatter Creek Bridge During Erection

KENMORE INTERCEPTOR

In 1965, the clean-up of Lake Washington east of Seattle was helped along by an essentially all-precast submerged bridge consists of 85-ton 120-foot-long hollow precast pipes as the superstructure (Fig. 5). These pipes were joined by precast pile caps supported on driven steel piles, with the whole structure residing 12 to 27feet below the lake surface. The sewer “intercepted” lateral outfalls from adjacent residential areas, and these lines fed into the pile caps. This sewer then eliminated the direct discharge of household septic tank waste into the lake.

The original design used a square section of pipe that weighed 120 tons, but this was refined in an alternative design using 16-sided sections that were hollow inside. These pipes were manufactured using a pulled-mandrel to form the inside surface of the pipes, a technique previously used to manufacture larger pretensioned hollow piles. The structure was obviously built entirely underwater and required divers to assist with the underwater work. Grouted (tremie concrete) connections were used to integrate the pile caps with the piles. Pairs of rubber O-ring seals connected the pipes (superstructure) with bell-and-spigot joints. Altogether, 229 sections of pipe (with precast pile caps) were used covering 4.65 miles in Lake Washington.

The structure continues to function today, and the construction technique has been used to build other underwater structures, most notably several outfalls for treated sewage.

Fig. 5 Interceptor Sewer

TRANSIT GUIDEWAYS

SEATTLE MONORAIL

As part of the 1962 World's Fair in Seattle, a new monorail was built to connect the fair site to downtown Seattle. ABAM and CTC won the contract to detail and manufacture the girders for the project. The guideway for the monorail, including the columns above the foundations, was designed to be removed after the fair closed. However, the facility has remained and today is nearly as iconic of Seattle as the fair's Space Needle.

The guideway comprises two simply-supported guideway beams per span, where one beam carries northbound vehicles and the other southbound vehicles (Fig. 6). This application was one of the first uses of precast, prestressed curved beams, and these beams comprise a hollow box-shaped cross section. The columns with integral crossheads were each precast horizontally on site, tilted up into position, and bolted to drilled shaft foundations. The guideway beams were then bolted onto the piers. The recesses for the bolts can be seen in the photo. The use of precast elements with careful attention to geometry yielded both an easily and simply constructed structure and a guideway with the appropriate ride quality.

Even though this structure was intended to be temporary and taken down in 1962 following the closing of the fair, the Seattle Monorail has survived the intervening 50 years in good shape and continues to carry daily traffic between downtown and the Seattle Center. In this case, the desire to easily dismantle the structure led to features, such as the precast columns/crossheads that today fall into the ABC category. Nonetheless, the longevity of the structure has proven durability of the details used, and that fact is helpful to engineers today, who are trying to build structures rapidly but also trying to make them durable.

Fig. 6 Erection of the Seattle Monorail

WALT DISNEY WORLD MONORAIL

The monorail at Walt Disney World in Orlando, Florida, comprises twin running beams supported on single-column piers (Fig. 7[1]). Both the columns and the beams are precast, and the beams are curved to accommodate the guideway geometry. The columns were erected on pile-cap CIP foundations that were built with large-diameter (27inches) vertical ducts to accept reinforcing bars that protruded from the bases of the precast columns. The columns were erected using externally bolted leveling jacks and an optical site and target system to ensure the tops of the columns were properly positioned. The superstructure is continuous with either five- or six-span units. The girders are curved both horizontally and vertically, plus they were built with superelevation, all features of which contribute to superior ride quality. Where the girders connect to the substructure, the crosshead is a steel cruciform shape that is stiff and strong for vertical gravity loads, adequately stiff for longitudinal loads, but torsionally flexible to accommodate the girder end rotations, thereby isolating one direction of the guideway from the other for train passage effects. The girders were erected using a knife-edge steel tab (as seen in the exploded view) and a lateral stay to properly position the girders. The joints were then concreted, and the continuous units were post-tensioned for the final integration.

The tolerances were so tight that the designers were accused of being “dreamers,” but working with the precast manufacturer, CTC, the team was able to deliver the structure with the desired tolerances to ensure excellent ride quality while simultaneously creating an elegant and graceful structure with minimal bulk. This again illustrates the synergy that can develop between the contractor and engineer to provide a superior solution and product.

In the late 1970s, the monorail was extended with the opening of Epcot Center. The design was essentially the same, but erection improvements were implemented by moving the knife-edge tab higher into a fully concreted end block in the girders. This put the center of gravity of the girder below the temporary support greatly simplifying the erection hardware. Additionally, an on-site precasting yard was used to avoid cross-country shipping of the girders.

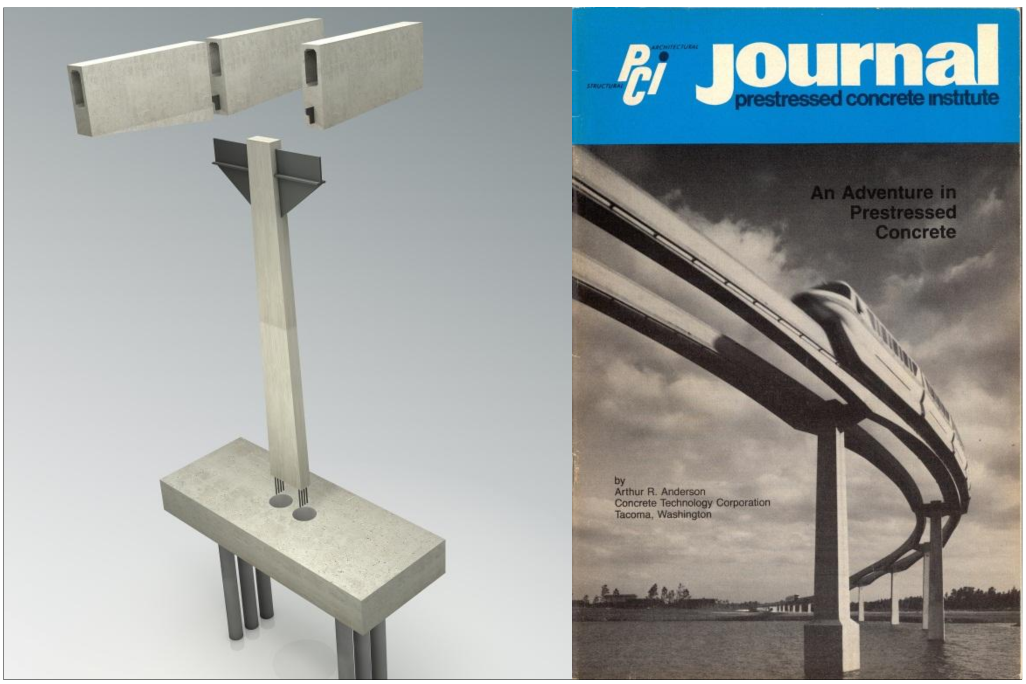

Fig. 7 Disney Pier Arrangement and Precast Guideway and Columns

VANCOUVER SKYTRAIN

The Vancouver, BC, SkyTrain project was built for the 1986 Expo, and the guideway connected Vancouver with four outlying communities via a 13-mile line, of which 10.3 miles are elevated (Fig. 8). For this guideway, a key ABC feature was the use of precast box-girder curved beams that contained direct-fixation inserts for track fasteners as built-in elements. The girders were manufactured to tight tolerances, which avoided second concrete pours in the field for rail-support plinths. The girders were cast in adjustable forms that could be configured to the required unique shape of each girder—in essence, “casting machines” as the beam manufacturer came to call them. This precision process saved both time and money for the project and helped bring the entire project in on time for the opening of the Expo.

The substructure was built largely of conventional CIP elements; however, the column cages were prefabricated and the longitudinal bars set into metal duct block-outs in the pile caps. These then were grouted and column forms erected and the columns cast. The superstructure comprises typical 30-meter spans but where necessary, 5-meter overhangs extend from piers to support a 30-meter drop-in span. These were typically used at surface-street crossings, as shown in Fig. 8.

Again a unique case-specific solution and blend of precast and CIP elements were used. The facility is still in use today.

Fig. 8 Vancouver, BC, SkyTrain

J. PAUL GETTY MUSEUM GUIDEWAY

In the early 1990s, BergerABAM (by then an affiliate of the Louis Berger Group family of companies) became the system contractor's engineer for the construction of a cable-operated guideway for the J. Paul Getty Museum near Los Angeles (Fig. 9)[3,4]. The alignment of the guideway was required to run parallel to an existing access road to minimize visual impact. Consequently, the alignment had nine curves with horizontal radii varying from 125 to 1,000 feet and had an average vertical grade of 7.2 percent.

The site included a very steep cross slope relative to the guideway, and this provided a significant challenge for the contractor. The original design had been completed using all CIP substructure with precast elements used for the superstructure. To simplify and accelerate construction of the piers, a precast pier cap design alternative was developed. The concrete columns and supporting drilled shafts remained CIP, but the pier cap was precast and relied on tight tolerances for fit up. Because the contractor "owned" and preferred this design, the tolerances for construction were easily accommodated. Jigs and templates were used to tie the internal reinforcing and form the caps. The erection of the pier caps proceeded smoothly using a single crane operated from a narrow access road as shown in Fig. 9.

Three days after the final punchlist was conducted on the facility, the 1994 Northridge earthquake struck putting the guideway to a full-scale lateral load test. The structure, which had been designed to a composite Los Angeles Uniform Building Code and Caltrans criteria, survived without damage.

Fig 9. Getty Center

MORE BRIDGES

REEDY CREEK BRIDGE

The bridge over Reedy Creek is located on Osceola Parkway and serves the main entrance to Walt Disney World's Animal Kingdom theme park. The bridge, which opened in 1997, is actually two parallel structures of a 1,000-foot total length, comprising 40-foot spans. A primary constraint during construction was the bridge had to be constructed from the top down to avoid impact to the creek bed below. Additionally, the structure had a low profile facilitating short spans and pile-bent-type construction.

The bridge had been completely designed and bid as a conventional design/bid/build contract. BergerABAM, working with the successful contractor, redesigned the bridge to use precast haunched deck panels. Per the original design, precast pier caps were used.

Supporting piles were 24-inch-diameter steel pipe piles. Each frame consisted of five 40-foot continuous spans, in which the pier caps were integrated using CIP concrete, and then a CIP topping was placed over the top of the entire bridge to form the deck surface and provide continuity. Key savings in the design/build alternative were due to the reduction in the number of steel piles through a change in the construction process. The contractor used a single crane jointly supported by the two parallel structures in lieu of using one crane per bridge.

Construction of both parallel bridges proceeded simultaneously with the crane working off a temporary erection platform supported by the permanent piles for the bridge (Fig. 10). The crane drove the piles, placed the pier caps, and placed the deck panels. The outer caps and panels were placed first, then the inner pieces were placed after the platform advanced.

The precast pier caps used the same cross section and were made in different lengths as needed. The caps had conical holes to provide for integration with the steel piles below. A reinforced concrete plug-type connection was used to integrate the piles and pier caps.

The haunched deck panels and precast pier caps were highly efficient for this type short-span structure. The simplicity of the design allowed the contractor to use one crane for the construction, and the scheme allowed the construction to be accelerated beyond that of the original design.

This design, which borrowed heavily from successful marine construction techniques, again illustrates a successful and near-optimal blend of construction materials, including steel pipe piles; precast pier caps; and precast, prestressed haunched deck panels with CIP topping. These were used in a manner that worked well with the contractor's method of erecting the structure, and as the photos illustrate, resulted in minimal disruption of the adjacent environment. Thus, ABC techniques can have benefits beyond just saving construction time.

Fig. 10 Reedy Creek Bridge

Northeast 36th STREET BRIDGE

The Northeast 36th Street Bridge in Redmond, Washington, crosses State Route 520 (SR 520), a divided highway in the Seattle area. The bridge has two spans and a total length of 315 feet. It is also 155 feet wide and in addition to the roadway, supports a broad park-like setting with a winding pedestrian path between Microsoft facilities on either side of the freeway. Accordingly, the gravity loads on the center pier are relatively large, and 14 columns are used to support the structure (Fig. 11). The columns are founded on a single combined footing in the median of SR 520; thus, construction access and maintenance of traffic were a challenge.

Working with the contractor, an alternative column design using precast elements was developed[5]. At the same time, the contractor was also working with the BergerABAM Highways for LIFE (HfL) grant team on the HfL project (see below), testing precast column bottom-of-column connection details. The testing had demonstrated that the columns had substantial gravity and seismic capacity despite the precast socket-type configuration. The contractor liked the column concept, because the columns were simple to set, especially with a purpose-built erection tubular frame as seen in the right-hand photo of Fig. 11. Thus, similar precast columns were proposed and used to build the center pier of the Northeast 36th Street Bridge saving about one month from the schedule compared to using CIP column construction. In this instance, the foundations and the pier cap were both CIP. Only the columns were precast.

Fig. 11 Northeast 36th Street Bridge

HIGHWAYS FOR LIFE BRIDGE - 12/118 (U.S. 12/I-5) GRAND MOUND BRIDGE

The Federal Highway Administration's Highways for LIFE Technology Partnerships Program awarded BergerABAM and its team a 2009 grant to bring to market a precast bridge pier design suitable for use with prestressed girder superstructures in high seismic regions[5]. This project culminated in a demonstration project built by the Washington State Department of Transportation (WSDOT) as a replacement bridge for U.S. 12 over Interstate 5 (I-5) at Grand Mound, Washington. The bridge is a two-span overcrossing using deck bulb-tees for the superstructure. The development of the precast pier was undertaken by WSDOT, University of Washington, CTC, Tri-State Construction, and was led by BergerABAM.

The pier system comprises precast columns using socket connections at the base and grouted duct connections at the top (Fig. 12). The socket connections may either be cast into spread footings or drilled shafts and are the same type of connections used for the Northeast 36th Street Bridge. The column, itself, may be either one piece or three pieces with splices in order to limit the piece size for lifting purposes.

After the columns are set and integrated with the foundation, the precast Stage 1 pier cap is set. Then, the upper column connection is completed to integrate the columns and Stage 1 pier cap in preparation for erection of the precast girders. After girder erection, the Stage 1 cap and protruding column bars are integrated with a Stage 2- or upper-stage cap that provides both longitudinal and transverse continuity for earthquake loading.

The central premise of the precast pier system is that the columns can be cast off site along with the cap beam. Then, these pieces are brought on site for erection minimizing construction time in the traveled way improving both maintenance of traffic and site safety for the traveling public. It is expected that this standardized bent system will become a viable tool in the toolbox for building these typical prestressed girder bridges in high seismic regions.

Fig. 12 Highways for LIFE Demonstration Project – U.S. 12 Bridge of I-5

CURRENT PROJECTS

BergerABAM has recently completed the design of two projects that uses ABC techniques; North Bridge over the Cedar River and the SR 520 Floating Bridge and Landings project.

NORTH BRIDGE

The North Bridge spans the Cedar River in Renton, Washington, and connects The Boeing Company factory and the Renton Airport. The project replaces an existing bridge structure that does not meet the needs of The Boeing Company facility. All aircraft that are assembled in the Boeing Renton facility are towed across the bridge to the Renton Airport for pre-flight activities before departing. The design and construction schedule for the new bridge was accelerated in order to meet Boeing’s increased production rate and plans for production of the new 737MAX. In response to the accelerated schedule, the new bridge was designed using precast columns, crossbeams, and full-depth precast deck panels.

The precast columns and crossbeams minimized the amount of in-water work time and meant that the work could be completed within the allotted fish window. Furthermore, the North Bridge has a low profile, requiring formwork below the ordinary high water elevation. Thus, the use of PBES is desirable environmentally, because the amount of CIP concrete over the river is minimized. The precast column-to-crossbeam and column-to-foundation connections utilized details developed as part of the HfL project described above. However, the crossbeam will be tub shaped with a CIP infill in order to minimize pick weight, and the bottom-of-column connection will be made to a CIP drilled shaft in-lieu of a CIP spread footing.

Use of a full-depth precast deck system replaced a conventional CIP concrete bridge deck system, saving significant time associated with forming, casting, and curing a CIP deck. Furthermore, the construction schedule for CIP decks depends on weather. The deck is scheduled to be cast in late fall/early winter, which is Western Washington’s wettest and stormiest season. It is estimated that use of the full-depth precast deck panels will save six weeks on the construction schedule.

SR 520 FLOATING BRIDGE AND LANDINGS (PIER 36)

Pier 36 of the SR 520 Floating Bridge and Landings project is a pair of two-column-bent structures founded on drilled shafts; one for westbound traffic and the other for eastbound traffic. The pier serves as the first land-based fixed pier and supports the west transition span that connects to the floating bridge to the west approach bridge. The pier is located in approximately 40 feet of water depth and is centered between the two northbound navigation channels located on the west end of the floating bridge. BergerABAM worked with the contractor to minimize time spent working in the navigation channel and to minimize the amount of CIP concrete over environmentally sensitive waters. The Pier 36 crossbeam section is 12 feet wide and 6 feet deep. It was determined that the crossbeam would be cast in stages. Stage 1 would be precast (i.e., the first 4 feet of depth) off site and then barged to the site for erection. Stage 2 would be CIP over the top 2 feet of final crossbeam depth.

The column-to-crossbeam connection utilizes the HfL details using fewer, large diameter vertical column bars grouted into corrugated metal ducts that extended full height of the stage 1 precast crossbeam section. The vertical column reinforcing extended through the stage 1 precast section and into the Stage 2 CIP crossbeam section.

CONCLUSIONS

This chronology of one firm’s “adventure” with precast, prestressed, and CIP concrete structures illustrates an evolution of thinking and creativity with respect to designing and building bridges. The notion of facilitating and even speeding up construction is not new, but is one where fruit may continue to be borne, and this is illustrated with the modern explosion of ABC projects and thinking. However, engineers and contractors have long been creative when it comes to building bridges. The main thoughts that we hope one takes from this article is that having tools in your toolbox is empowering, and you are only limited by your creativity and imagination. That said, the old carpenter's adage "measure twice, cut once" applies to ABC more than ever. We hope you have enjoyed this tour through a few of our projects, and we hope you have picked up a few concepts or perhaps have gained confidence in concepts you might be currently pondering.

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