SCAN TEAM REPORT
NCHRP Project 20-68A, Scan 11-02

Best Practices Regarding Performance of ABC Connections in Bridges Subjected to Multihazard and Extreme Events

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Executive Summary

Introduction

The National Cooperative Highway Research Program (NCHRP) Project No. 20-68A, U.S. Domestic Scan Program, is a broad initiative that considers innovative transportation-related practices used by some transportation agencies and potentially could be adopted by other agencies to help advance their own state-of-the-practice. The purpose of the scan program is to collect and facilitate sharing of information and technology among the states and other transportation agencies and identify actionable items related to the dissemination of the findings and the implementation of the best practices identified in the scan.

One of the innovative practices a number of states use is accelerated bridge construction (ABC), which is intended to reduce the time and overall costs of bridge construction and its impact on the traveling public and improve work-zone safety, quality, and durability, among other factors. Working more efficiently is consistent with the Federal Highway Administration's (FHWA's) Every Day Counts initiative.

ABC practices often involve using prefabricated components that must be connected effectively to form a well-integrated bridge system that resists design loads. Connections of prefabricated elements are particularly critical under extreme event loading, such as high waves, tidal or storm surges, earthquakes, high winds, blasts, and other largely lateral forces acting on bridges. This scan focused on connections that are resistant to this type of loading.

This report presents a summary of the initial findings, recommendations, and planned implementation actions of a domestic scan conducted from March 25 to 31 and April 22 to 28, 2012, to identify successful and emerging ABC connections that are able to resist multi-hazard (MH) loading and extreme events.

Scan Purpose and Scope

This scan's overall objective was to identify connection details that are used in the United States for ABC and perform well under natural or man-made extreme events, loading (e.g., those under waves and tidal or storm-surges), seismic events, blasts, and other large forces.

A desk scan was conducted prior to the site visits. The desk scan included a brief review of the most relevant reports, papers, and web materials. The main part of the desk scan was an extensive survey of nine states, each with a known interest in ABC, a history of ABC-related activities, and in which one or more extreme event is likely to occur.

The scan team met in Washington, DC, on November 17, 2011, to discuss the desk scan report, which analyzed and summarized the survey's results. In addition to discussing the scan's mission and the site visit schedule, the team also developed a list of amplifying questions and finalized the list of states and institutions to be included in the scan.

The scan team visited Massachusetts, Florida, Utah, Washington State, and Nevada, the first two during the first week of the scan and the latter three during the second week. Several representatives from California joined the scan meeting in Nevada. Texas and South Carolina participated in the meetings in Massachusetts and Florida, respectively via web conference calls. During the team's meeting in Massachusetts, the FHWA-funded State University of New York at Buffalo (SUNY Buffalo) study on MH loading and the seismic performance of segmental bridge members was presented and discussed via a web conference call.

The scan visits consisted of meetings with officials, engineers, contractors, suppliers, and researchers conducting studies of various ABC connections. The team visited select bridge construction sites, completed ABC projects, and research facilities. The findings presented in this report are based on the face-to-face discussions, presentations, responses to amplifying questions, site visits, and supplementary materials that were provided to the scan team.

General Findings and Observations

ABC connection performance under MH loading is a multifaceted subject encompassing many interrelated topics, most of which are emerging. To help identify and communicate the scan results, the team grouped the findings into the following topics:

- Extreme Load Consideration for Bridges and ABC Connections
- ABC Connection Details
- ABC Connection Maintenance
- Standardization of ABC Connection Details and Processes
- ABC Connection Research
- Innovative ABC Connections
- Monitoring ABC Connections and Prefabricated Bridge Elements and Systems
- Other Findings

Extreme Load Consideration for Bridges and ABC Connections

MH loading combinations are considered only to a limited extent even for conventional bridges because of a lack of guidelines and a general belief that the probability of simultaneously occurring multiple extreme loads is low. The team could not identify any information on ABC connection design under MH loading. Even under seismic loading, no specific American Association of State Highway and Transportation Officials (AASHTO) guidelines exist for ABC connection design, despite the relative maturity of earthquake engineering of bridges. In fact, restrictions on splicing longitudinal column reinforcement within the plastic hinge zone in seismic design category (SDC) C or D in the AASHTO Guide Specifications for LRFD Seismic Bridge Design severely limits the implementation of ABC in high seismic regions. This is consistent with the scan's findings that there is a correlation between the level of seismicity and the level of implementation of ABC practices. The lack of widely accepted, well-developed, and proven ABC connection details has prevented extensive application of ABC in high seismic zones.

An FHWA-funded study is in progress at SUNY Buffalo, to address the gap in knowledge, develop MH design guidelines, and establish a platform to include MH loading in load and resistance factor design (MH-LRFD) for highway bridges. The study's focus is bridges in general; it is not specific to ABC or ABC connections. The study is primarily analytical because of a lack of extensive field and research data. The limit states and load factors developed in this study are aimed for eventual integration in AASHTO LRFD.

ABC Connection Details

Although ABC generally has been applied to a small fraction of the overall bridge population, numerous ABC connection types have been used by various states. Several states have adopted some of the connection details from the FHWA manual on ABC for their ABC practice. Some states allow for unrestrained movement of the superstructure under lateral loads, and the bearing connections are designed for vertical loading only. Under a storm surge, the approach some states take is to allow for uplift of the superstructure.

The scan team identified three types of precast connections during the scan: column to pier cap, column to pile cap, and column to pile shaft. In one connection type, the column is embedded into the adjacent member (i.e., pile shaft, footing, or cap beam). A second connection type consists of grouted couplers that may be embedded into the column or the adjacent member. The third connection type uses a precast column that has longitudinal bars extending from it. The bars are inserted into corrugated metal ducts in the adjacent member and the duct is filled with grout.

Some states with more ABC experience have refined connections based on their field experience. When necessary, they have relied on codes other than AASHTO requirements when designing and detailing some of the ABC connections.

ABC Connection Maintenance

The relatively short history of ABC makes it difficult to generalize about ABC connection maintenance issues or lack thereof. ABC connections are generally perceived to perform the same as conventional connections over time because they are mostly intended to be emulative. Nonetheless, some states inspect precast elements and joints annually rather than biennially, which is the normal frequency. They document field observations and use lessons learned to refine connection designs for future ABC projects.

Despite the confidence in emulative ABC details, agencies take many precautionary measures to minimize maintenance problems and improve durability. Joint details and construction procedures are evolving based on field experience. This trend is expected to continue.

Standardization of ABC Connection Details and Processes

Standardization of ABC applies to design and details, in addition to the process by which an agency selects the ABC alternative for a project.

With the expanding popularity of ABC, states are realizing that standard connection details need to be developed, although their philosophies differ. While some states believe that preapproved standard ABC connections should be provided, others believe that leaving flexibility in design and detailing could encourage widespread ABC use. More states appear to subscribe to the former view. Some of the standard details that are being developed do not meet AASHTO requirements. Some states do not allow couplers in plastic hinge regions of columns when the bridge is in SDC C or D because of AASHTO restrictions.

The process by which ABC is selected over conventional construction, although not specific to ABC connections, is important and relevant to this scan's objective. Decision-making tools are evolving at national and state levels and are becoming available. User costs are generally considered and used as a means of justifying ABC, although in many instances the initial cost is the primary consideration.

ABC Connection Research

Research focusing primarily on the seismic performance of ABC connections and members has been conducted. High-early-strength concrete is being studied, with a focus on developing standard mixes that can be used at closure pours to join prefabricated reinforced concrete deck elements.

ABC connections can be categorized as emulative or non-emulative connections. Emulative connection seismic research has focused on providing full continuity at the connection for the transfer of critical forces. Precast reinforced concrete columns embedded into footings, piles, or pier caps have been studied under cyclic loads with satisfactory results. Large-diameter bars anchored in corrugated metal ducts or standard couplers of various types for longitudinal bars also have been used. Various methods of converting multi-girder pier cap connections into integral pier caps also have been studied.

The versatility offered by precast members has encouraged research on non-emulative connection response under seismic loads. Post-tensioned segmental columns utilizing different details have been studied under slow cyclic and shake table loading. In some cases, sliding and rocking at joints are allowed to improve energy dissipation. In other studies, novel materials, like fiberreinforced concrete and built-in rubber pads, have been used in segmental columns to improve performance beyond that of conventional columns (i.e., by minimizing damage).

Various researchers have studied concrete-filled steel and fiber-reinforced polymer (FRP) tubes under slow cyclic and shake table loading. The column models are embedded into footings to provide full moment transfer. Results have demonstrated that the column-footing connections performed successfully.

Other means to improve seismic performance beyond emulative design has included the use of high-performance concrete, shape memory alloy reinforcement, and steel pipe pins in lieu of conventionally reinforced pins.

Innovative ABC Connections

ABC provides the opportunity to embrace innovation. In addition to research on using high-performance concrete, high-performance metallic materials, and the FRP materials previously described, various forms of innovative precast double-T girders are being considered for bridge superstructures. Folded-plate steel girders and concrete-filled FRP-tube arches are being implemented in selected bridges.

Post-tensioning has been used in bridge girders for decades. Many states are making use of post-tensioning in ABC through post-tensioned bridge decks and abutments. Transverse post-tensioning of girders in cap beam zones is considered one method of converting multi-girder pier cap connections into integral pier caps.

Base isolation, which has been used for conventional bridges, is being considered as a viable alternative to help reduce demand on ABC connections under seismic loads.

The FHWA Highways for LIFE (HfL) and Innovative Bridge Research and Deployment (IBRD) programs have served as mechanisms for field implementation of promising innovative concepts that have been developed based on research.

Monitoring ABC Connections and Prefabricated Bridge Elements and Systems

Some states conduct instrumentation and long-term health monitoring of prefabricated bridge components and their connections on a selected basis only when innovative, unconventional elements are utilized in the bridge. The purpose of gathering data on novel bridges, bridge components, and bridge connections is to determine any unexpected behaviors and learn about their responses. The general view about monitoring is that it may not be necessary, particularly when ABC connections are emulative.

Some of the bridges that are moved using self-propelled modular transporters (SPMT) are monitored during the moves to ensure that no overstress occurs in bridge components.

Other Findings

Extensive communication among different stakeholders (e.g., designers, contractors, top management, fabricators, industry, and the public) appears to have been the key to the successful planning and execution of past ABC projects. Involving contractors early in the design and planning process alleviated issues and encouraged contractor participation in ABC, both because of the reduced financial risk and the shared risk associated with using new methods.

In some cases, the remoteness of precast plants relative to the job site might discourage the adoption of ABC. Although site casting of precast members may be viable, it does require added quality assurance and quality control.

More states are becoming aware of the importance of education and training for design and inspection of ABC projects. ABC design tools are also critical; many states are developing them to become an integral part of their bridge design manuals. Many lessons are being learned about the best practices of ABC. Despite the challenges associated with ABC, there is a great deal of enthusiasm and desire to use ABC. FHWA's HfL and IBRD programs are valuable vehicles for applying and showcasing ABC projects.

Recommendations

The scan team makes the following recommendations based on the scan and team discussions following the visits.

- **Continue research on MH load combination.** Studies should provide insight into any considerations that are unique to ABC connections. Once the research results are available and the potential methodologies for incorporating MH into LRFD are developed, an NCHRP project to transfer this research into AASHTO guidelines should be undertaken.

- **Establish a national center on ABC under MH loading.** The main goals of this center would be to:

    - Coordinate and integrate ABC research and development of design guidelines for MH loading consideration
    - Ensure that emerging ABC connections are simple and practical
    - Develop a library of standard ABC connections details
    - Provide assessments of different connections
    - Collect, compile, interpret, and develop a database of field performance of ABC connections
    - Develop performance characteristics of ABC components and connections for performance-based design methods
    - Coordinate with AASHTO to develop bridge design and construction specifications

- **Undertake extensive outreach to promote ABC to the bridge contracting community through The Associated General Contractors of America.** FHWA's Every Day Counts initiative has set a vision of which ABC is an important component. The outreach could be included in the mission of the center discussed in the previous recommendation.

- **Expand the support of demonstration projects utilizing various ABC connections by FHWA's HfL program.** This will help showcase successful ABC design and implementation and promote ABC in areas where extreme loads are prevalent.

- **Continue to do research on emulative design to facilitate its implementation in AASHTO specifications.** In turn, this will enable ABC to be fully implemented in regions of high seismicity and other extreme loads.

- **Consider using innovative details, high-performance grouts, concrete, metals, and composite materials for future development**, even though emulative design is the most appropriate initial focus for codifying ABC connections. Innovative methods and materials have the potential to meet or exceed the target performance levels of emulative design.

- **Investigate and inspect ABC projects in the field frequently, document performance data, and identify lessons learned until a sufficiently large database of field performance of ABC connections is compiled.** This effort could be undertaken in collaboration with the FHWA Long-Term Bridge Performance monitoring program to utilize the tools and processes that have become available in recent years.

- **Update the AASHTO Guide Specifications for LRFD Seismic Bridge Design for implementation of ABC in SDCs B, C, and D.**

- **Perform research and field monitoring and develop design and construction specifications for the use of high-early-strength concrete and grouts in closure pours for ABC connections.**

- **Develop guidelines for shipping with respect to weights and sizes of prefabricated components.**