PERFORMANCE OF ACCELERATED BRIDGE CONSTRUCTION CONNECTION IN BRIDGES SUBJECTED TO ESTREME EVENTS (NCHRP DOMESTIC SCAN 11-02)

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Abstract

This paper summarizes the findings from NCHRP Project 20-68A, Domestic Scan 11-02 on "Best Practices Regarding the Performance of Accelerated Bridge Construction (ABC) Connections in Bridges Subjected to Multi-Hazard and Extreme Events". The objective of this Domestic Scan was to identify connection details that can be used for ABC and which perform well under extreme events, including waves and tidal or storm surge loads, earthquakes, blast, and other large lateral forces. Topics covered include findings on published ABC design guidelines, standard ABC components and connections, research results, field case studies, lessons learned, and Scan Team recommendations.

Introduction

The U.S. Domestic Scan Program is initiated by the National Cooperative Highway Research Program (NCHRP) Project No. 20-68A to collect and disseminate information about innovative transportation-related practices that are used by some agencies and that could be potentially adopted by other transportation agencies to help advance their state-of-the-practice.

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Accelerated bridge construction (ABC) is one of innovations exercised by a number of states to reduce the duration and overall cost of bridge construction and its impact on the traveling public, improving work-zone safety, quality, and durability, among others [30]. ABC is consistent with the aim of the Federal Highway Administration (FHWA) "Everyday Counts" initiative. To expedite construction, prefabricated bridge elements are essential. However, these elements must be effectively connected to provide structural continuity such that the entire bridge system can effectively resist design loads. Connections of prefabricated elements are particularly critical under extreme event loading such as those acting on bridges subjected to high waves, storm-surges, earthquakes, high winds, blast, and other forces where the lateral loads are substantial.

Domestic Scan 11-02 was aimed at connections that are resistant to this type of loading. The objective of the scan was to identify successful and emerging connections for prefabricated bridge components that are able to resist multi-hazard (MH) loading and extreme events. This paper presents the highlights of the scan activities, its findings, recommendations, and planned implementation.

Scan Objectives and Scope

The overall objective of the scan was to identify connection details that are used in the United States for accelerated bridge construction (ABC) and which perform well under extreme natural and man-made events loading such as those under waves and tidal or storm surges, seismic events, blast, hurricanes, fire, etc.

The project consisted of a "desk scan," scan team meetings, visits to different states, compilation of information, and development of a scan project report. The purpose of the desk scan was to conduct a brief review of the most relevant reports, papers, and web materials; further refine the focus of the scan; and identify the states and agencies to be visited or interacted with to maximize the return from the scan effort. The main part of the desk scan was an extensive survey of nine states with a known history of activities and interest in ABC in which one or more extreme event are relevant. The survey results were analyzed and summarized in a desk scan report, which was discussed at a meeting of the scan team in November 2011. In addition to the discussion of the mission of the scan and the schedule of the visits, a list of amplifying questions was developed at the meeting and the list of states and institutions to be included in the scan was finalized. The scan team travelled to several states for meetings, while others were contacted by conference calls. The states the scan team visited directly, listed in chronological order, were: Massachusetts, Florida, Utah, Washington, and Nevada, with the first two included in the first week of the scan and the latter three in the second week. The state of California participated through several representatives who joined the scan meeting in Nevada. In addition, the states of Texas and South Carolina participated via web conference calls during scan team meetings in Massachusetts and Florida, respectively. The states that provided information for this scan are marked in Fig. 1. The Federal Highway Administration-funded study on MH loading and seismic performance of segmental bridge members at the University of Buffalo was presented and discussed at the meeting of the scan team in Massachusetts via a web conference call.

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

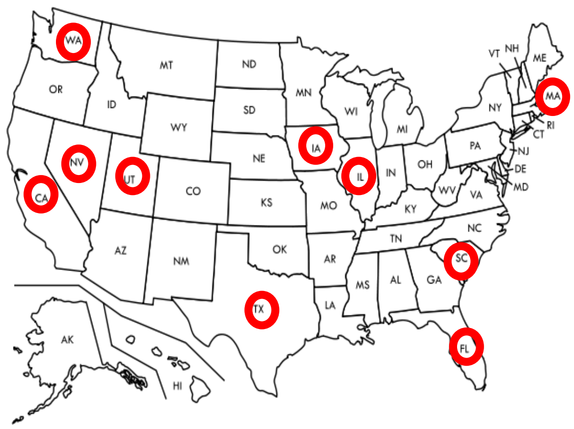

Figure 1. – States providing data on ABC connection practice

General Findings and Observations

ABC connection performance under MH loading is a multi-facetted subject encompassing many inter-related topics, the majority of which are emerging. To help identify and communicate the scan results the findings were grouped into eight topics:

1. Extreme load consideration for bridges and ABC connections
2. ABC connection details
3. ABC connection maintenance
4. Standardization of ABC connection details and processes
5. ABC connection research
6. Innovative ABC connections
7. Monitoring ABC connections and prefabricated bridge elements and systems
8. Other findings

1 - Extreme load consideration for bridges and ABC connections

Multi-hazard loading combinations are considered only to a limited extent even for conventional bridges because of a lack of guidelines and the general belief that the probability of simultaneous occurrence of multiple extreme loads is low. No information on ABC connection design under MH loading could be identified. Even under seismic loading, no specific AASHTO guidelines exist for ABC connection design despite the relative maturity of earthquake engineering of bridges. <u>In fact, one of the key findings from the scan is that restrictions on</u>

splicing longitudinal column reinforcement within the plastic hinge zone in seismic design category (SDC) C or D in the AASHTO Seismic Guide Specifications severely limit the implementation of ABC in high seismic regions of the country. This is consistent with the findings of the scan 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.

To address the gap in knowledge and develop MH design guidelines, an FHWA-funded study is in progress at the University at Buffalo, NY, to establish a platform to include MH loading in LRFD for highway bridges (MH-LRFD) [1]. The focus of the study is on bridges in general and is not specific to ABC or ABC connections. The study is primarily of analytical nature because of a lack of extensive field and research data. The current AASHTO LRFD framework is being used for eventual integration of limit states and load factors that will be developed in this study. To help guide the study, a survey of state bridge engineers was conducted [3] and a workshop of state bridge engineers was held. The survey helped establish the current views and practices across different states for MH design. Both multiple simultaneous and cascading events were discussed. Fig. 2 presents a sample of the survey findings for simultaneous action of scour, storm surge. It is evident from the survey that there is considerable variation among the states with respect how extreme load combination is considered depending on the geographical location and extreme load type.

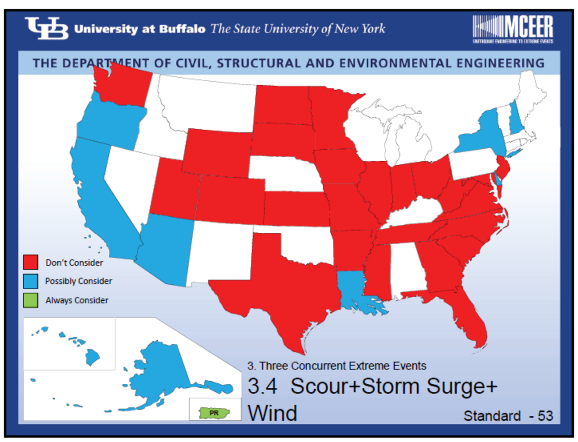

Figure 2. – Survey results for consideration of scour, storm surge, and wind combination

2- ABC Connection Details

Although ABC has been generally applied to a small fraction of the overall bridge population throughout the country, numerous ABC connection types have been used by various states. Some of the connection details from the recently published FHWA manual on ABC are being adopted by several states [2]. Some states allow for unrestrained movement of the superstructure under lateral loads and design bearing connections for vertical loading alone. Under storm surge, the approach taken by some states is to allow for uplift of the superstructure.

Three types of precast column to pier cap, column to pile cap, and column to pile shaft connections were identified during the scan. In one connection type, the column is embedded into the adjacent member (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 (Fig. 3). The third connection type uses longitudinal bars extending from a precast column that are inserted into corrugated metal ducts in the adjacent member and the duct is filled with grout.

Some states with a longer history of ABC use have refined connections based on field experience. They have relied on codes other than AASHTO when necessary in design and detailing of some of the ABC connections.

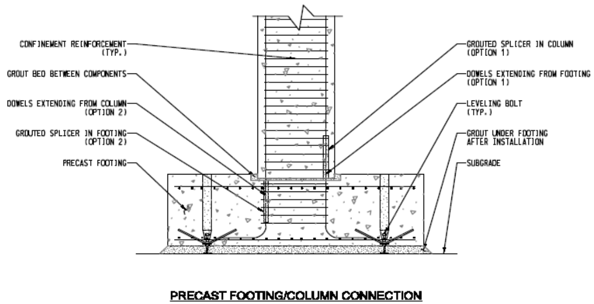

Figure 3. – Precast column to precast footing connection with grouted couplers

3- ABC Connection Maintenance

Due to the relatively short history of ABC application, it is difficult to make a broad statement about maintenance issues or lack thereof in ABC connections. Generally ABC connections are perceived to perform the same as conventional connections over time because they are mostly intended to be emulative. Nonetheless, some states conduct annual inspection of precast elements and joints rather than the normal biennial inspection to monitor. Field observations are documented and lessons learned are used to refine connection designs for future ABC projects. Despite the confidence in emulative ABC details, many precautionary measures are taken to minimize maintenance problems and improve durability. Joint details and construction procedures are evolving based on field experience. This trend is expected to continue.

4- Standardization of ABC Connection Details and Processes

Standardization of ABC applies to design and details in addition to the process by which the ABC alternative is selected for a project.

With expanding popularity of ABC, the need to develop standard connection details is being realized in different states, although philosophies differ among them. 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. There appear to be more states subscribing to the former view. Fig. 4 shows a standard detail adopted in Massachusetts. An example of precast column being placed in cast-in-place footing as part of a Highway For Life project is shown in Fig. 5. 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 the objective of the scan. Decision making tools are evolving at national and state levels and are becoming available. User costs are generally considered and utilized as a means to justify ABC, although in many instances the initial cost is the primary consideration.

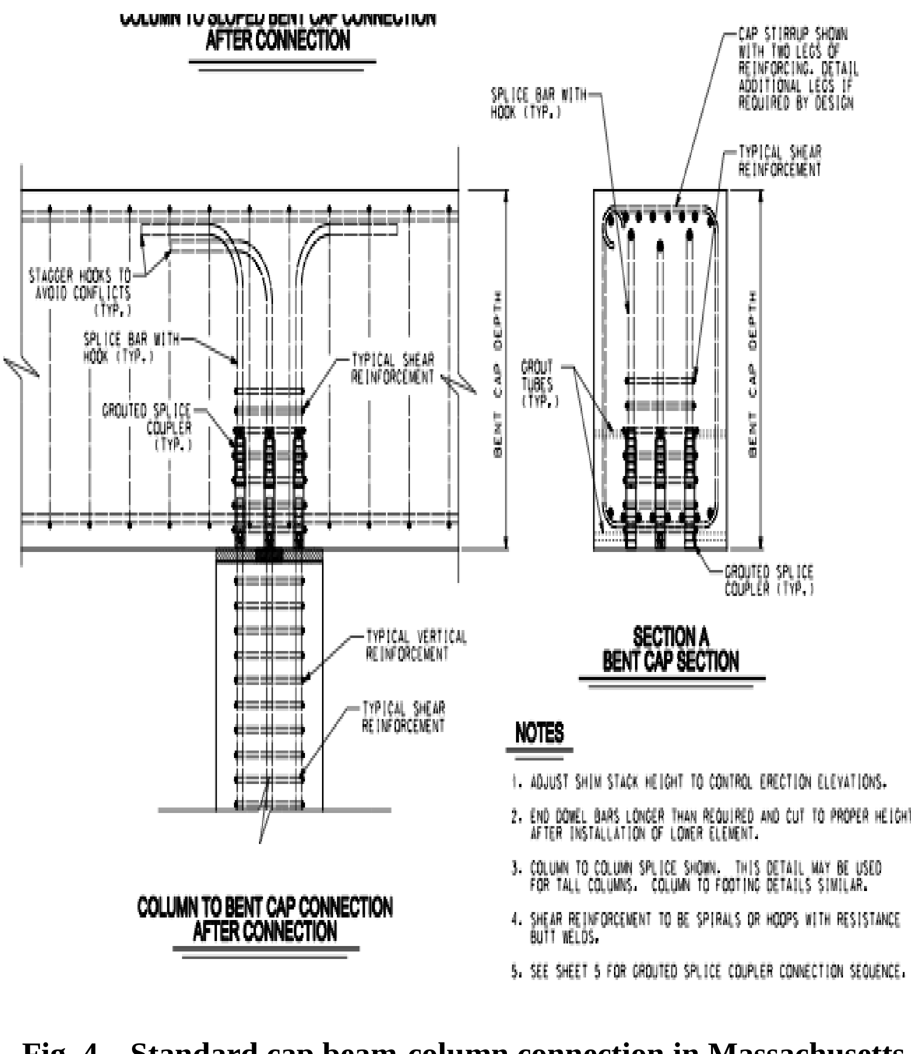

Fig. 4 – Standard cap beam-column connection in Massachusetts

Fig. 5 – Precast column embedded in cast-in-place footing in the State of Washington

5- ABC Connection Research

Research has been conducted on ABC connections with a focus mostly on seismic performance of ABC connections and members. Studies are being carried out on high-early strength concrete with the aim of developing standard mixes that may be used at closure pours joining prefabricated reinforced concrete deck elements.

ABC connections may be placed into two categories - emulative and non-emulative connections. Emulative connection seismic research has focused on providing full continuity at the connection for transfer of critical forces. Precast reinforced concrete columns embedded into footings, piles, or pier caps (Fig. 6) have been studied under cyclic loads with satisfactory results. Using couplers in the plastic hinge zones (Fig. 7) has shown promising results. Also large-diameter bars anchored in corrugated metal ducts or standard couplers of various types for longitudinal bars have been used. Various methods to convert multi-girder pier cap connections into integral pier caps have been also studied (Fig. 8).

The versatility offered by precast members has encouraged research on non-emulative connections 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 such as fiber-reinforced concrete and built-in rubber pads have been used in segmental columns to improve performance beyond that of conventional columns by minimizing damage. Concrete filled steel and FRP (fiber-reinforced polymer) tubes have been studied by various researchers under slow cyclic and shake table loading. The column models are embedded into footings to provide full moment transfer. Results have demonstrated successful performance of column-footing connections. Other means to improve the 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.

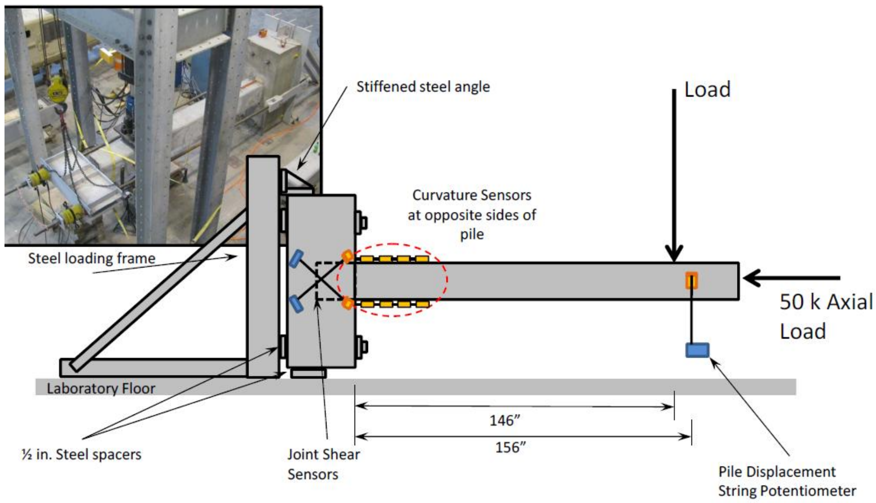

Fig. 6 – Pile cap beam connection model tested at the University of South Carolina

Fig. 7 – Precast column-footing connection model with headed bar couplers tested at the University of Nevada - Reno

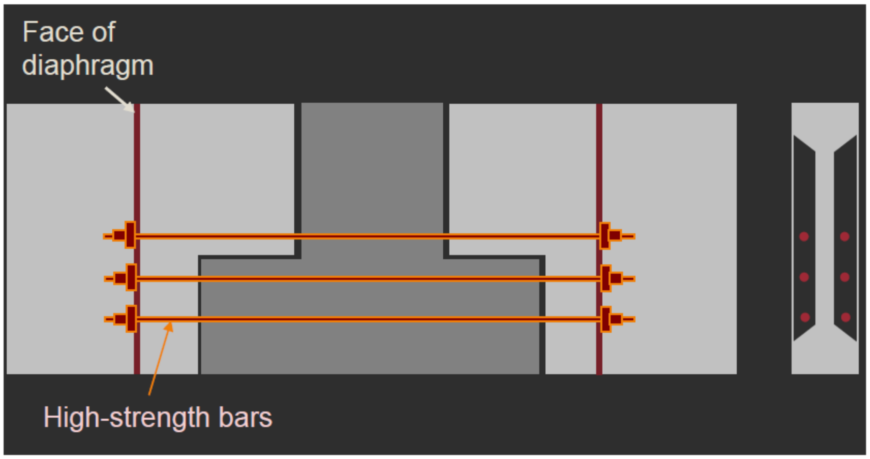

Fig. 8 - Superstructure/cap beam connection with high-strength bars tested by Iowa State University

6- Innovative ABC connections

ABC provides the opportunity to embrace innovation. In addition to research on using high performance concrete, high performance metallic materials, and FRP materials previously described, various forms of innovative precast double-T girders are being considered for bridge superstructure. 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 are considered as one of the means to convert multi-girder pier cap connections into integral pier caps. Base isolation, although it 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) Innovative Bridge Research and Deployment (IBRD) programs have served as a mechanism for field implementation of promising innovative concepts that have been developed based on research.

Research on adopting advanced materials in ABC connections has focused on different materials, concepts, and details. Post-tensioned segmental columns with sliding joints have shown promising results for their damping and recentering capability (Fig. 9). Precast concrete-filled fiber-reinforced polymer composite tube columns (Fig. 10) save construction time by reducing the need for formwork, yet they have shown to reduce damage under earthquake loading. Another detail to reduce damage in the plastic hinge of ABC columns is incorporation of rubber pads that are normally used in base isolation, but changing their role form shear deformable elements to flexural members replacing concrete in the plastic hinge (Fig. 11). Recent research has shown superior performance of these pads over conventional plastic hinges.

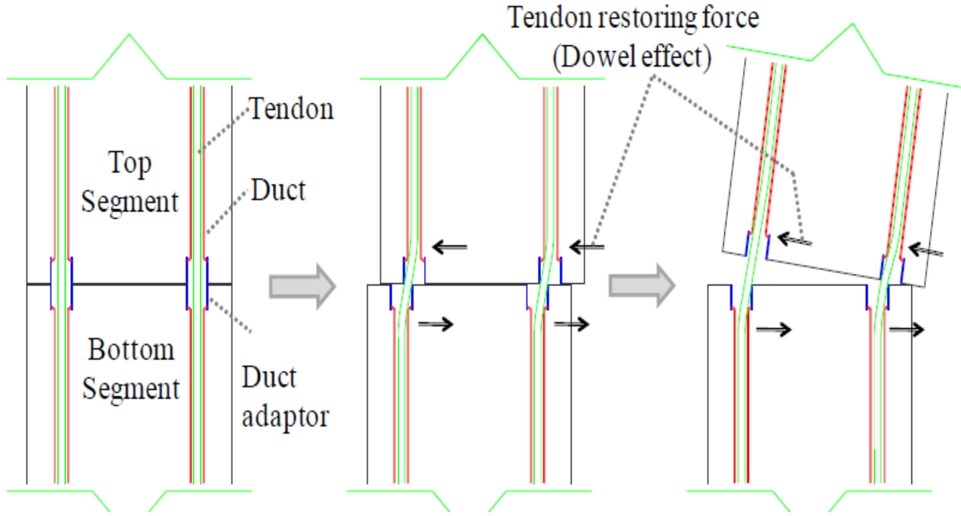

Fig.9 – Segmental column connection with sliding joints tested at the University at Buffalo

Fig. 10 – Precast concrete filled FRP tube column placed in precast footing at the University of Nevada - Reno

Fig.11 – Segmental column model with rubber pad a shake table at the University of Nevada - Reno

7- Monitoring ABC connections and prefabricated bridge elements and systems

Instrumentation and long-term health monitoring of prefabricated bridge components and their connections are conducted by some states 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 behavior and learn about their response. The general view about monitoring is that it may not be necessary, particularly when ABC connections are emulative.

Short-term monitoring of movements is conducted during SPMT moves and placement of precast superstructures to ensure that no overstress occurs in bridge components.

8- Other Findings

Extensive communication among different stakeholders such as designers, contractors, top management, fabricators, industry, and the public appears to have been the key to successful planning and execution of past ABC projects. Early involvement of contractors in the design and planning process has alleviated issues and has encouraged participation of contractors in ABC because of the reduced financial risk and sharing of risk associated with new methods. In some cases 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 requires added quality assurance and quality control.

More and 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 and are being developed by different states to become an integral part of their bridge design manuals. Many lessons are being learned about best practices of ABC. Despite the challenges associated with ABC, there is a great deal of enthusiasm and desire to use ABC. The FHWA Highway for Life program and the Innovative Bridge Research and Deployment (IBRD) program provide valuable vehicles to apply and showcase ABC projects.

<u>Team Recommendations</u>

The following recommendations are made based on the scan and discussions during scan team meetings following the visits:

1 Research needs to continue on MH load combination. Studies should provide insight into any considerations that are unique to ABC connections. Once research results are obtained and potential methodologies to incorporate MH in LRFD are developed, an NCHRP project to transfer research into AASHTO guidelines should be undertaken.

2 A national center on ABC under MH loading should be established. The main goals of this center would be to (a) coordinate and integrate ABC research and development of design guidelines for MH loading consideration, (b) ensure that emerging ABC connections are simple and practical, (c) develop a library of standard ABC connections details, (d) provide assessment of different connections, (e) collect, compile, interpret, and develop a data base of field performance of ABC connections, (f) develop performance characteristics of ABC components and connections for performance based design methods, and (g) coordinate with AASHTO to develop bridge design and construction specifications.

3 The FHWA "Everyday Counts" program has set a vision which includes ABC as an important component. Extensive outreach to the bridge contracting community needs to be undertaken to promote ABC. This could be included in the mission of the center discussed under Recommendation 2.

4 The FHWA "Highways for Life" program, and similar programs, should expand its support of demonstration projects utilizing various ABC connections. This would help showcase successful ABC design and support implementation with the goal of promoting ABC in regions of the country where extreme loads are prevalent.

5 Continue to do research on emulative design to help implement AASHTO specifications so that ABC can be fully implemented in regions of high seismicity and other extreme loads.

6 Even though emulative design is the most appropriate initial focus for codifying ABC connections, the use of innovative details, high-performance grouts, concrete, metals, and composite materials should be considered for future development. Innovative methods and materials have the potential to meet or exceed target performance levels of emulative design.

7 Until a sufficiently large data base of field performance of ABC connections is compiled, frequent field investigation and inspection of ABC projects should be conducted, performance data be documented, and lessons learned be identified. This effort may 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.

8 Update the AASHTO Seismic Guide Specifications for implementation of ABC in SDC Zones B, C and D.

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

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

Conclusions

A clear picture of the state of practice on design and construction of ABC connections to resist extreme loads was obtained through Scan 11-02. It was found that design for multi-hazard loading has yet to materialize because of a lack of design procedures and guidelines. Current AASHTO provisions limiting the use of mechanical couplers in column plastic hinges in areas of moderate and high seismicity was noted as an important barrier preventing the earthquake prone states from using ABC. Significant research on emulative and innovative ABC connections has been conducted. It is recommended that a central source to gather and interpret information about construction, detailing, education, design guidelines, and research on ABC be formed and serve as a clearing house to further promote ABC.

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