MDOT RC-1610

Accelerated Bridge Construction and Structural Move - Workshop

MARCH 2014

Research

Department of Civil & Construction Engineering
College of Engineering and Applied Sciences
Western Michigan University

Accelerated Bridge Construction and Structural Move - Workshop

Appendices

Project Manager: Matthew Chynoweth, P.E.

Submitted to:

MDOT

Submitted by

Haluk Aktan, Ph.D., P.E.
Professor
(269) 276 – 3206
haluk.aktan@wmich.edu

Upul Attanayake, Ph.D., P.E.
Associate Professor
(269) 276 – 3217
upul.attanayake@wmich.edu

Abdul Wahed Mohammed, EIT
Graduate Research Assistant
(269) 276 - 3204
abdulwahed.mohammed@wmich.edu

Western Michigan University
Department of Civil & Construction Engineering
College of Engineering and Applied Sciences
Kalamazoo, MI 49008
Fax: (269) 276 – 3211

APPENDIX A

WORKSHOP SURVEY

WESTERN MICHIGAN UNIVERSITY

Department of Civil and Construction Engineering
College of Engineering and Applied Sciences

Assessment Survey

Accelerated Bridge Construction (ABC)/Structural Slide and Move - Workshop
December 09, 2013

Your feedback is important to us; please rate your experience before, during, and after the workshop.

1. What was your ABC knowledge level coming into the workshop? ______________________________

2. Were you involved with previous ABC projects? ______________________________________

3. Have you ever participated in ABC demonstration projects? _____________________________

4. Have you ever participated in any workshop/meeting/presentations on ABC? __________________

5. What is your affiliation? State agency ☐ Local agency ☐ Consultant ☐ Contractor ☐ MDOT ☐

6. What is your current position? ____

How do you agree to the following statements? (Please leave answerer blank if it does not apply)	Agree 1	2	3	4	Disagree 5
7. I received information about this workshop in a timely manner	①	②	③	④	⑤
8. The dates and times offered worked well for me	①	②	③	④	⑤
9. I had the appropriate background knowledge for this workshop	①	②	③	④	⑤
10. Material was presented at an appropriate level	①	②	③	④	⑤
11. Handouts were useful and relevant	①	②	③	④	⑤
12. Material was presented clearly	①	②	③	④	⑤
13. The workshop was an appropriate length	①	②	③	④	⑤
14. The workshop increased my understanding of this topic	①	②	③	④	⑤
15. Instructors were knowledgeable	①	②	③	④	⑤
16. Instructors were well prepared	①	②	③	④	⑤
17. Facilities were adequate	①	②	③	④	⑤
18. I would recommend this workshop to others	①	②	③	④	⑤
19. Overall, I am very satisfied with the workshop	①	②	③	④	⑤

20. Comments:

____

____

____

____

Thank you for your participation.

APPENDIX B

WORKSHOP PRESENTATION SUMMARIES

GREGORY JOHNSON, MDOT CHIEF OPERATIONS OFFICER

Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

MDOT is 108 years old and has been designers and constructors of the interstate system. MDOT's role as mobility managers is to recognize the impact to the economy and strengthen the economy by getting the projects delivered in a faster manner. Thus, MDOT is interested in deploying ABC technologies in future projects. In addition, MDOT is working at the national level through the AASHTO subcommittee on Bridges and Structures to advance ABC/PBES technologies. Slide technology is a tool for MDOT to become efficient mobility managers. The slide projects are expected to be tools in MDOT's tool box that will provide customer service and customer expectations for a future MDOT. The slide technology will be considered for projects where an extensively long detour, such as 70 miles, is required to get around a closed bridge.

In 2014, two bridge slide projects will be delivered in the Grand region using the CM/GC contracting method. MDOT is implementing the slide technology for the first time. Hence, for the first two slide projects, the CM/GC contracting method will bring a contractor to help MDOT. MDOT foresees the future bridge slide projects to be design/bid/build; thus, it requires the contracting industry and those delivering the projects to be knowledgeable of the technology. The industry needs to understand that slide technology is not a specialized tool; rather it is a project delivery alternative that will be included in the future program, which can be deployed as needed based on site conditions.

One of the major drivers behind the implementation of slide technology in Michigan is FHWA through its initiative Every Day Counts (EDC). EDC's goal is that 25% of bridges constructed with Federal Aid need to incorporate at least one ABC component. MDOT has been stepping on the path of that process, and the implementation of slide technology is another step in that process.

MDOT in October 2012 approved an ABC policy document. The policy made ABC/PBES part of MDOT business. The MDOT ABC policy makes a proactive statement to the MDOT scoping personnel to identify the components of a project that are appropriate for ABC, or to indicate why a bridge will not qualify for the ABC program. The personnel are doing an outstanding job to identify projects that are fit for ABC and are providing a good response.

MATTHEW CHYNOWETH, MDOT BRIDGE FIELD SERVICES ENGINEER

Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

MDOT has the ABC policy engaged and is working towards making it part of their normal business practice. This work is being administered by a committee/partnership that includes members from MDOT, consultant and industry staff, and it was established by David Juntunen in 2011. The committee supervised the selection of a few in-progress MDOT ABC projects and is regulating the means and methods of selection for performing the slides-in projects.

The purpose of this workshop and MDOT's on-going work towards ABC is to learn from demonstration projects. This will help in standardizing the new technologies. MDOT needs to gain more knowledge and additional experience in order to develop a program approach. In the call for projects, MDOT requires the project selection to be based on the feasibility of ABC for projects. If ABC is not justified for a project, then MDOT requires a rationale for that decision.

Section 7.01.19 of the Bridge Design Manual includes ABC and PBES considerations. This section will be updated in the future with additional information after evaluating additional means and methods for ABC. MDOT also needs to develop a performance management strategy for ABC projects. For example, additional standards may be required for inspecting UHPC joints, post-tensioning, launching technology, etc., for assuring the quality and durability.

MDOT has two slide-in projects scheduled for the summer of 2014 in the Grand region. MDOT, with consultant and industry input, has developed a special provision for sliding a prefabricated structure. This special provision is sufficiently general and in the future will be labeled as *previously approved*. Moreover, it will be on MDOT's website to be used on ABC projects. MDOT is also involved in developing jacking force calculations based on static and kinetic friction coefficients. This will allow selecting appropriate material and jacks for the jacking operation. In addition, MDOT is working on SPMT special provision. A few of the requirements in the slide-in special provision are the following:

- Working drawings, calculations, and submittals
- Move operations manual. This is to ensure that MDOT inspectors, MDOT engineers, contractor, superintendent, and contractor's engineer are coordinated. Thus, if any issue arises during the slide, all the associates on-site will be clear on their responsibilities to mitigate that issue.
- Geometry control and monitoring plan
- Contingency plan
- Trial horizontal slide
- Movement of superstructure requirements
- Allowable tolerances.

MDOT is currently working on updating the Project Scoping Manual for evaluation of ABC/PBES techniques with respect to: (1) Site and Structure Considerations, (2) Work Zone Safety and Mobility, (3) Cost, (4) Technical Feasibility, (5) Seasonal Constraints and Project Schedule, and (6) Environmental Issues. MDOT's current mobility policy deals with defining if a project is a major project. Currently, the criteria included in the mobility policy are: (i) Volume to capacity ratio of more than 0.80, (ii) Work zone travel delay of more than 10 minutes, (iii) Any corridors of significance, and (iv) LOS is D/E or during construction drops from A to C. However for ABC, MDOT is focusing more on the user delay and work zone safety and will be including the criteria: (i) User delay costs, (ii) Project schedule (lengths/events), and (iii) Part-width construction, detour, or temporary bridge.

The MDOT recommended activities in progress are the following:

- Achieve industry buy-in. MDOT will be conducting workshops and technical conferences of this nature and will allow enough time for the local industry to become comfortable and knowledgeable using new ABC technologies. At this time, MDOT will be using the CMGC contracting method for the first two slide-in projects. Following these projects, based on the contractors' experience and perspective, the Design-Bid-Build contracting method will be used.

- Think like a contractor. Traditionally the means and methods were a contractor's responsibility. However, for ABC, the owner (MDOT) needs to develop means and methods thoroughly during the design phase itself by considering equipment capabilities/capacities.
- Plan a program of projects. This will inform the local industry that MDOT's business model is changing.

MDOT currently identifies the following barriers and challenges to ABC implementation:

- Thinking like a contractor, considering constructability during the design phase
- Insufficient knowledge and experience in detailing connections, specifying tolerances, tracking durability, designing curvilinear geometry, and accounting for negative moment continuity
- Availability of precast contractors
- Construction staging difficulties
- Designing a component size adequate for transport and erection
- Contractor proposing CIP instead of PBES following award
- Ability to innovative during design without becoming too prescriptive on means and methods
- Costs. User delay cost versus construction cost, and the equipment cost based on availability

MDOT is also involved in the process of developing guidelines for choosing ABC. The Michigan Accelerated Bridge Construction Decision-Making (Mi-ABCD) process was developed and a software platform was developed under MDOT's research project by Western Michigan University. Dr. Haluk Aktan is the Principal Investigator of the research project. (The details of the project are presented in a later section under Dr. Aktan's presentation.) The tool developed from the research project is planned to be used during MDOT's call for projects process and project scoping. The research is continuing at Western Michigan University under Dr. Aktan to expand the program so that slide-in and SPMT ABC methodologies are included.

MDOT, from their past ABC projects, learned the following aspects that prompted them to initiate the process of partnering and shared risk:

- Choose suitable projects and associated material applications.
- Target capabilities of contractors/fabricators.
- Analyze effects of cost and schedule.

So far, MDOT has constructed 3 bridges utilizing ABC techniques. These projects utilized PBES and are listed below:

- Parkview Avenue over US 131 in 2008
- US 31 BR over White Lake in 2011
- M-25 over the White River in 2011

The future of ABC at MDOT includes the following activities to be performed in 2014 and thereafter:

- Implementing three structural slide-in projects during 2014
- Implementing one bridge project involving PBES with IBRD funding
- Identifying a suitable candidate bridge for first SPMT move and implementing
- Evaluating standard joint and connection details
- Developing Decked I-beam using Carbon Fiber Prestressing Strands and UHPC under the ongoing pooled fund research project approved by FHWA (participating states: IA, MI, MN, OR, WI, and one pending)

MDOT PANEL REPRESENTING TRANSPORTATION SERVICE CENTERS

The MDOT panel discussed expectations, anticipated field operations, and public outreach and input for the three slide-in projects in Michigan scheduled for 2014. The MDOT panel consisted of associates (Eric, Tom, and Greg) from MDOT Transportation Service Centers that were responsible for the slide-in projects. The panel provided expectations or concerns related to respective slide-in projects and answered questions that followed.

As mentioned earlier, there are two projects in the Grand region that are: (1) US 131 over 3-mile road NB and SB: superstructure slide-in of two single-span structures, and (2) M-50 over I-96: a two-span structure slide-in project. Another slide-in project is: M-100 over the railroad.

US 131 NB and SB over 3-Mile Road Project

Two-lanes will be maintained on US 131 except in special situations. Uninterrupted traffic flow will be maintained on US 131 during the construction of the replacement bridge that is built on temporary supports adjacent to existing structure. One-lane will be maintained when the traffic is diverted off the freeway onto the new bridge. The traffic will remain on the new structure for a period of 5 days or less before the slide-in. Both the projects in Grand region are on high profile corridors. The major parameters leading to slide-in technology at these locations were the detour and Maintenance of Traffic (MOT) considerations.

M-50 over I-96 Project

The project involves a complete interchange reconstruction. This is a main intersection for the local community along with one of the largest Park & Ride Lots. The main goal of the project is to keep the traffic open to the extent possible. The new bridge will be built adjacent to existing bridge. Before the slide, the traffic will be diverted to the new bridge to demolish the old bridge, and construct the new substructure. MDOT TSC conducted the first public engagement meeting in November 2013 for this project and obtained a very positive response. The project required significant coordination with the public and emergency services. Developing and presenting animated videos of the slide-in process benefited the public outreach. From the public perspective, the mobility was the primary factor for the positive response. The bridge is planned to be maintained while other activities at the original alignment are completed, and then the bridge slide-in will be performed with a very minimal weekend closure.

M-100 over the Railroad Project

The site is in Potterville, MI. Currently; the project is in its design stages under MDOT's in house design team. The existing structure is a 3-span bridge with a total length of 155 ft and 70° skew. The site requires increasing underclearance. The new bridge will be a single span structure of around 107 ft long. The M-100 is not a high profile corridor. However, the bridge replacement project will be a significant impact to local community since the bridge connects a school and all the emergency services to Potterville. In this project, the planned detours are significantly longer. These constraints dictated the selection of slide-in technology for this project. The MOT scheme at this project is that the new bridge superstructure will be built on temporary supports and will be used to maintain traffic while the M-100 Bridge is demolished. After building new CIP abutments, the new bridge will be slid into place. MDOT is planning to perform the slide in a 6-hr window.

In all three slide-in projects, diverting traffic onto a new structure allows maintaining traffic on the same route during existing bridge demolition, pile driving, and substructure construction. In Michigan, common practice is to use piles for the bridge foundations.

JOHN ALMEIDA, AECON INFRASTRUCTURE GROUP INC., CANADA

The key points presented are the lessons learned from the contractors' perspective in performing ABC projects using SPMTs. Please use the presentation slides given in Appendix D while reviewing the information presented in this section. The presentation is a case study: HWY-417 Rapid Bridge Replacement (FHWA terminology for ABC).

Background

Highway 417 bridge, located in Ottawa, Ontario under the jurisdiction of the Ontario Ministry of Transportation, was replaced using SPMT technology. Two bridges located at Krikwood Avenue and two bridges located at Carling Avenue in Ottawa were originally constructed in 1959. After minor repairs and rehabilitation in 1983 and 2002, the Ontario Ministry of Transportation procured an $18M rehabilitation contract. Aecon Infrastructure Group, Inc. was the contracting agency for this project. The scope of work was (1) rapidly replacing four bridges, (2) widening of substructures to accommodate an extra traffic lane, (3) construction of four replacement bridges in an adjacent lay down areas, and (4) resurfacing of asphalt and site restoration.

Two discrete moves of two bridges included the following: Location 1 was replaced during July 6th to 7th, 2013, and Location 2 was replaced during 13th to 14th, 2013. Each new steel multi-girder bridge with a cast-in-place concrete slab weighed 400 t (440.90 ton or 881.85 kips). Aecon had 110 employees, at peak, working on this project. The contractor took the lessons learned from first weekend into the second weekend and improved the performance. To assure having sufficient stroke for the lift (at the final location), the contractor incorporated an SPMT system that had jacking in the carrier but also self-climbing towers that lift/drop in 6 in. increments. The SPMT moves enabled minimal traffic disruption to an estimated ADT of 136,000 compared to another project delivery alternative that was to stage the construction with long-term lane closures. In one case, two bridges were moved with a construction window of 14 hours (Saturday 6pm to Sunday 8am).

Moving the bridges is not time consuming in these types of projects, and proceeds relatively quickly. The time consuming activities are details such as backfill, time requires for asphalt to cool down to commence other operations, such as lane markings, placing barriers, guard rails, etc. The plan was to remove the existing superstructure using a set of SPMTs, transport, and place it on the temporary supports of the new superstructure while the new superstructure was supported on another set of SPMTs adjacent to the bridge site. However, the temporary supports were wider than the existing superstructure. A thorough investigation was performed to identify suitable modifications to the temporary substructure to shore the existing bridges. The details considered were the bearings, bearing distances, and differential elevations between the bearings.

The number and type of people required to make these kinds of jobs happen are critical. The lane closures are allowed only at night to perform the work. Several activities need to be performed, and detailed schedules need to be prepared prior to performing the work. The work includes: (1) pre-ABC procedures, (2) ABC procedures, and (3) post-ABC procedures. This work takes around 6 months from the contractors' perspective. The contracting community needs to check their courage based on the number of people they have and the number among those who will be willing to take a season of night work.

The Ontario Ministry of Transportation specified operational constraints are as follows: Close one lane at 5pm; full closure at 6pm (Saturday).

- Median lane in each direction open by 11am (Sunday); Lane 2 in each direction open by 12pm (Sunday)
- Remaining lanes and ramps open by 6am (Monday)
- Only base course asphalt required when the bridge is first opened to traffic.

Incentives and Disincentives

The incentives and disincentives typically tend to motivate contractors, but when things go wrong, they actually demotivate the contractors.

The following is a list of penalties or disincentives specified by the Ontario Ministry of Transportation:

- Penalty for early closure: An initial penalty of $1000, and thereafter a further penalty of $100 per minute for the time outside the permitted closure window that the traffic lanes are not open to traffic
- Penalty for late opening: On each occasion when the contractor fails to reopen the traffic lanes by the specified time, an initial penalty of $10,000. Then, if the traffic lanes are not open within next 15 minutes a further penalty of $1000, and thereafter, a further penalty of $100 per minute
- Total disincentives of $280,000 per weekend if the lanes are not opened to traffic according to the specified constraints.

The Ontario Ministry of Transportation incentivized the bridge move. The contractor can earn up to $80,000 as an incentive per weekend if the lanes are opened to traffic within the specified time window.

Planning

Detailed planning is required from start to completion. It is very important to select appropriate methodology, type of equipment, and workers with specific skills for the work to be performed. For example, identifying proper equipment, tools, and procedures for pavement marking when the asphalt is hot. Planning needs to include minute details such as installing transition rails at the approach that may require a temporary concrete barrier. Here it is crucial to identify the equipment and number of workers required for the job and at specific times. Although these details seem to be simple, these are the ones that will consume the time and may lead to crossing the construction time window.

Things can happen such as SPMTs failing due to bearing pressure or any other issue. These events are highly complex and require highly skilled workers to tackle them. It is very crucial to select appropriate specialty contractors and highly skilled crews.

Planning for pre-ABC work: At least six-months of non-stop detailed planning and work need to be performed. The planning was performed with *5-minute* milestones including if-else mitigation measures. Several field engineers, who are solely responsible to keep track of progress, need to be present on-site. In addition, strategic resource management of equipment and labor is essential. For example, it is important to choose rubber tired excavators as they are light, about 20 t (22.05 ton or 44.09 kips), fast, and leave a small footprint. They can be used on freshly placed asphalt; whereas, the track mounted equipment while excavating will rip-off the asphalt and may require padding, etc. In addition, details such as sufficient lighting on rubber tired equipment and a water truck to cool down asphalt need to be considered.

Geotechnical

The temporary supports located in the staging area shall have adequate bearing capacity to prevent any settlement. The Ontario Ministry of Transportation had a specification limiting the maximum differential settlement to 2 mm (0.079 in.) between two points in the temporary structure.

Concrete sill pads (precast blocks) or reinforced concrete footings were utilized to limit the settlements. After the project, the reinforced concrete footings are dug out and disposed. However, the concrete sill pads (part of a proprietary shoring system) are reusable. In general, the factored bearing capacity of the soil shall be twice the applied bearing pressure in the staging area (i.e., Factor of Safety of 2). During this project, the organic material at the staging area was removed and a granular base was placed to achieve the required baring capacity. The distributed load from the concrete sill pads (3.94ft × 3.94ft) and the granular base was adequate to limit temporary support settlement. Further, the granular base was critical for SPMT moves. The thickness of the granular base was calculated based on the loads from shoring and the SPMT moves, and the bearing capacity of the soil.

During the moves, at any given instance, the load from SPMTs was estimated to be 100 kPa (2.09 ksf). A 0.6 m (2 ft) thick granular base was laid on the move path to reduce the effective pressure on existing ground (i.e., from 100 kPa (2.09 ksf) to 40 kPa (0.84 ksf)). Lines for the move path were marked to direct SPMTs in planned path. Also, these lines aid in ensuring the SPMTs are traveling on sufficiently thick rolled plates and/or sufficiently covered utilities.

Frequent precision survey is critical. Double-checking is critical for the skew angles, bearing elevations, and span lengths. In addition, bearings were installed (using tie downs, friction clamps, etc.) on the bottom flange of the girder before the move. These processes ensure accurate elevations and proper placement of the structure.

The temporary shoring was selected considering the needs for controlling elevation differences and the existing bridge demolition. Note that the existing bridge needs to be demolished on the temporary shoring. However, this option is not cost effective in terms of the loads that temporary shoring needs to withstand during demolition. Another approach is to cut the old bridge on the temporary shoring, lifting, placing on the ground, and then demolishing it.

Sequence of Operations of the Ontario Projects

Three sets of 24 axle lines of SPMTs were used for the complete operation of two bridge moves at each location in Ottawa, Ontario. Detailed planning of SPMT moves was performed. It was necessary to consider the dimensions of existing and new bridges to prevent conflicts on the move path and in/out of the staging area. It is essential to keep in mind that all the operations involved in ABC are at nights or on the weekends.

Pre-ABC Lift Operations

The pre-ABC lift operations were completed in 3 weekends of lane closures. The following is a list of pre-ABC lift activities:

- Remove approach slabs and asphalt.
- Excavate backfill.
- Saw-cut and stabilize the abutment walls and/or backwalls.
- Backfill the existing abutment walls and/or backwalls including sub-drain installation and connection.
- Divert the sub-drain below.
- Place temporary hot mix asphalt.

Operations during ABC Lift

The ABC operation was completed on a weekend with full lane closure. The following is a list of ABC activities:

- Excavate backfill.
- Remove existing superstructure and transport to staging area.
- Transport new superstructure from staging area and erect to final position.
- Backfill with granular material.
- Place hot mix asphalt on structures (lanes and shoulders).
- Place hot mix asphalt on approaches.
- Install temporary concrete barriers.

The backfilling is a time consuming operation and a critical activity in the ABC window. A minimum amount of asphalt and backfill should be removed to assist bridge move because it will reduce the amount of post-ABC work on backfilling and pavement restoration. A prudent approach is to use marker tapes to demarcate the excavation area to prevent extensive excavation.

The saw-cutting of abutment walls is another critical activity. A highly skilled worker is required for this operation because a slight deviation in the cutting angle may lead to unintended damages to the structure as well as unsafe conditions. It is necessary to maintain accurate tolerances at the abutment location when the new structure is brought in. This is to ensure accurate grouting operation to connect the existing abutment with the new superstructure.

The Post-ABC Operations

The post-ABC lift operations were completed in 3 weekends of lane closures. The following is a list of post-ABC lift activities:

- Excavation
- Grading and placement of granular base for approach slabs
- Construction of approach slabs using rapid set concrete or precast approach slabs

- Placement of hot mix asphalt on approach slabs and on exterior portions of the structure (future lane 4 and shoulder)
- Placement of median barrier walls on approach slabs using rapid set concrete and embedded electrical work.

It should be understood that to perform a minute amount of work on a weekend at least 50 workers are required. Mangers need to ensure that the workers are available for all the weekends during construction duration.

Future of ABC in Ontario, Canada

ABC is becoming the standard practice on high ADT facilities due to less traffic disruption, grater public satisfaction, and cost and time savings.

A pilot project is being contemplated to move a rigid frame bridge. In this case, a new set of footings and pedestals are cast on top of old footings. The rigid frame that includes the superstructure and substructure is built in the staging area, moved onto the pedestals, and connected using a dry-fit mating process. The structure in this case is lifted via precast lifting pockets in the vertical members of the frame. Another pilot project is being contemplated to build the full structure including the footings in the staging area and moving to the final position. The new footings are pressure grouted and doweled into the existing footings at the final position. In these cases, the bridge may weigh up to 1400 t (1543.24 ton or 3086.47 kips).

FRIDO DE GREEF, PROCUREMENT MANAGER, MAMMOET USA INC.

This presentation describes procuring transport and lift solutions. The section presents information about the process and timing for dealing with specialty subcontractors such as Mammoet USA, Inc.

Background

Planning is the critical aspect for accomplishing successful ABC projects. It is also essential to communicate with a heavy lift or heavy haul contractor in early planning phase of an ABC project. A lack of detailed planning may lead to delay in the project as well as a financial loss.

It is important to indicate that there will be a shortage in available heavy lift/move equipment such as SPMTs during 2015 to 2020 due to a boom in the gas industry. An alternative to using SPMT is skidding.

For *clustered ABC projects* involving heavy lift/moving specialty subcontractors, about 25% of the project cost goes to the specialty subcontractors, and one-third of the specialty subcontractor's cost goes to mobilization and demobilization. Planning is essential to have reduced weight of the structure that requires less equipment that will lead to significant cost savings in terms of mobilization or demobilization costs.

Advantages of ABC from Mammoet Experience

Project managers at Mammoet save about 10% on their contracts' costs by implementing the concept of *"Planning it right and doing it right will save money."* Mammoet USA in Rosharon, TX moved to a 32000 ft^2, 1200 ton (2400 kips) office building consisting of 2 stories. This building, while being mostly furnished during the move, was moved into place using SPMTs. The facility was fully functional within 2 weeks of the move. During the move only a 2° (maximum limit) forward slant was allowed for the facility. The project resulted in 8-9% of savings in the project cost (including the transportation costs) because of implementing the SPMT move. Other benefits realized from the project were not requiring a temporary office site while the new structure was being built, and preventing extra liability due to construction exposure in limited space of the existing facility.

ABC Move Methods

The available technologies related to moving structures are divided into: (1) vertical methods, (2) horizontal methods, and (3) monitoring methods for movement/ stresses of structures. Considering the vertical move methods, the technologies available are the following:

- Cranes
- Tower Systems
  - Strand Jacks
  - Gantry Systems
- Jacking
  - Climbing Jacks
  - Titan Systems
  - JS 500

Considering the horizontal move methods, the technologies available are the following:

- Trailers
  - SPMTs
  - Conventional Trailers
- Skidding or slide
- Barging

In addition, various inexpensive monitoring technologies are utilized to ensure the bridge is moved or transported in a safe manner.

To explain the ABC move methods, we will consider an example project consisting of a bridge weighing 2500 tons (5000 kips) and located about 500 miles from a major equipment hub. In this example, the bridge is transported from land to a barge, and then at the final destination, the bridge will be lifted up 60 ft from the barge to its final position. For this project, available technologies and their associated costs are compared.

The following tables present the impact level on owner's budget associated with various parameters involved in respective move methods (based on Mammoet's previous projects):

Table 1 Vertical Move using Cranes

Impact on Owner's budget / Parameters for Move methods	Extremely high	Very strong	Strong	Moderate	Very low
Typical required engineering hours			✓		
Training and experience level for engineers, operators, and support staff				✓	
Availability (2015 to 2020)		✓			
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)	✓				
Installation of specialty equipment		✓			
Speed of execution				✓	
Demolition possibilities				✓	
Rating for Overall Impact to Budget	**40 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when cranes are used in a project:

- Ground bearing pressure
- Lifting points
- Weight chart for respective cranes. This is essential as it shall be preplanned with respect to structure weight and any overweight because of lifting/placing radius.

Table 2 Vertical Move using Strand Jacks

Impact on owner's budget / Parameters for move methods	Extremely high	Very strong	Strong	Moderate	Very low
Typical required engineering hours		✓			
Training and experience level for engineers, operators, and support staff	✓				
Availability (2015 to 2020)		✓			
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)				✓	
Installation of specialty equipment			✓		
Speed of execution			✓		
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**36 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Strand Jacks are used in a project:

- Ideal for limited access (hard to reach areas)
- Leads to extreme savings when implemented early in the design phase
- Mobilization and demobilization is very cheap: Each equipment weighs about 4 ton (8 kips), and 5 to 6 equipment can be transported on one truck without load permits.
- Computer controlled and has a *slow* lifting process. The process is not as fast as Cranes.
- Can be used for bridge removal. Additional equipment is not required for lifting or lowering the bridge. However, extreme engineering design is required.
- Stand jacks can lift a bridge about 3 ft in one stroke that takes about 10-12 minutes.

Table 3 Vertical Move using Multiple Strand Jacks per Tower

Impact on owner's budget / **Parameters for move methods**	**Extremely high**	**Very strong**	**Strong**	**Moderate**	**Very low**
Typical required engineering hours		✓			
Training and experience level for engineers, operators, and support staff	✓				
Availability (2015 to 2020)			✓		
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)				✓	
Installation of specialty equipment				✓	
Speed of execution			✓		
Demolition possibilities				✓	
Rating for Overall Impact to Budget	**42 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when implementing Multiple Strand Jacks per Tower in a project:

- Strand jacks with 100 ton (200 kips), 300 ton (600 kips), and 900 ton (1800 kips) capacities can be combined per tower.
- Hammer head tower design required for this technology is ideal for bridge projects.
- Use of electrical power is possible.
- Light load support cranes are needed for bringing the materials on to the tower.

Table 4 Vertical Move using Gantry Systems

Parameters for move methods / Impact on owner's budget	Extremely high	Very strong	Strong	Moderate	Very low
Typical required engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff			✓		
Availability (2015 to 2020)			✓		
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)				✓	
Installation of specialty equipment			✓		
Speed of execution			✓		
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**44 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Gantry Systems are used in a project:

- Requires extremely stable ground
- Capacity up to 1250 ton (2500 kips)
- Ideal for lighter deck removal with gantry-skidding beams mounted on girders
- Limited lift height
- Project with 3 or 4 hydraulic points only (not 2, or 5 or more) for lifting operation.

Table 5 Vertical Move using Climbing Jacks

Parameters for move methods / Impact on owner's budget	Extremely high	Very strong	Strong	Moderate	Very low
Typical engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff			✓		
Availability (2015 to 2020)				✓	
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)					✓
Installation of specialty equipment				✓	
Speed of execution		✓			
Demolition possibilities		✓			
Rating for Overall Impact to Budget	**46 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Climbing Jacks are used in a project:

- Pressure points for both structure and support shall be well calculated and/or predictive.
- Height restricted: Can go up to 2-3 ft per stroke.

- Labor intensive and *slow*: Each stroke takes about 2-3 minutes based on the access to the jacks.
- Cheap for mobilization and demobilization
- Cheap in engineering
- Structural demolition is possible.
- Good quality of Jacking Wood that is used as bracing is crucial for safe operation.

Table 6 Vertical Move using Titan Systems Jacking

Impact on owner's budget / Parameters for move methods	Extremely high	Very strong	Strong	Moderate	Very low
Typical engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff		✓			
Availability (2015 to 2020)				✓	
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)			✓		
Installation of specialty equipment			✓		
Speed of execution		✓			
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**40 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Titan Systems Jacking is used in a project:

- Ideal in combination with SPMTs
- Lift capacity up to 2400 ton (4800 kips)
- Extremely stable and support friendly.

Table 7 Vertical Move using JS 500 Jacking

Impact on owner's budget / Parameters for move methods	Extremely high	Very strong	Strong	Moderate	Very low
Typical engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff			✓		
Availability (2015 to 2020)				✓	
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)		✓			
Installation of specialty equipment			✓		
Speed of execution		✓			
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**40 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when JS 500 Jacking is used in a project:

- Ideal in combination with SPMTs
- Stable
- Computer controlled jacking: Differential tolerance of 4 mm (0.16 in.) can be achieved between the jacks.
- 500 ton per tower
- Lifting above 33 ft requires additional bracing.
- More fork lifts and labor are required to increase the speed, because the bracing blocks need to be moved on the JS 500s quickly for increased speed of the operation.
- Tie down to structure is required at temporary of fixed points.
- The technology shall to be considered during the design phase itself.

Table 8 Horizontal Move using SPMTs

Impact on owner's budget / **Parameters for move methods**	**Extremely high**	**Very strong**	**Strong**	**Moderate**	**Very low**
Typical engineering hours needed		✓			
Training and experience level for engineers, operators, and support staff		✓			
Availability (2015 to 2020)	✓				
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)	✓				
Installation of specialty equipment			✓		
Speed of execution				✓	
Demolition possibilities				✓	
Rating for Overall Impact to Budget	**34 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when SPMTs are used in a project:

- Ground bearing pressure: Steel plates are very essential for the move path.
- Extremely versatile
- Structural demolition is possible.
- Bracing between SPMTs and structure is extremely important.
- Air filled tires
- Capacity of about 30 ton (60 kips) per axle line
- 360° steering capability

- Titan system combination feasibility
- Hydraulic systems can be customized for 3 or 4 point set up.
- Spacers can be incorporated for cost savings. Spacers are 6-line bases that can take load similar to SPMTs, but do not have wheels. These can be used for staging areas and can save some money for mobilization/demobilization and equipment rental.

Table 9 Horizontal Move using Conventional Trailers

Parameters for move methods / **Impact on owner's budget**	**Extremely high**	**Very strong**	**Strong**	**Moderate**	**Very low**
Typical engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff				✓	
Availability (2015 to 2020)				✓	
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)			✓		
Installation of specialty equipment			✓		
Speed of execution			✓		
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**46 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Conventional Trailers are used in a project:

- 10 ft wide (i.e., 2 ft wider than SPMT); therefore, more stable than SPMTs, if used as a single trailer
- May require load permits because of extra width. However in general, mobilization and demobilization for this technology is cheap as they are pulled behind the trucks. This technology will be much cheaper if equipment is available locally.
- Less steering possibilities in most conventional trailer types
- Different loading chart for different types and brands: These are more flexible than SPMTs.

Table 10 Horizontal Move using Skidding or Sliding

Parameters for move methods \ Impact on owner's budget	Extremely high	Very strong	Strong	Moderate	Very low
Typical engineering hours needed			✓		
Training and experience level for engineers, operators, and support staff			✓		
Availability (2015 to 2020)				✓	
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)					✓
Installation of specialty equipment				✓	
Speed of execution		✓			
Demolition possibilities			✓		
Rating for Overall Impact to Budget	**48 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when a Skidding or Sliding technique is used in a project:

- Great solution for value engineering: Very cheap way of moving
- It will be slower than other horizontal move methods.
- Push or pull points shall be strong enough.
- Combination/Installation with jacking is possible.
- Capacity ranges from 100 ton (200 kips) to 750 ton (1500 kips).
- If the new bridge cannot be constructed close enough and/or on the same elevation of the existing bridge, then the Skidding or Sliding technology may not be applicable.

Table 11 Horizontal Move using Barging

Parameters for move methods \ Impact on owner's budget	Extremely high	Very strong	Strong	Moderate	Very low
Typical engineering hours needed		✓			
Training and experience level for engineers, operators, and support staff		✓			
Availability (2015 to 2020)		✓			
Mobilization and Demobilization (Transport of specialty equipment to and from the project site)	✓				
Installation of specialty equipment				✓	
Speed of execution	✓				
Demolition possibilities		✓			
Rating for Overall Impact to Budget	**28 out of 100** (Note: low rating means least preferred)				

The following are the key considerations when Barging is used in a project:

- May be affected by weather related issues such as heavy rain and water level/current of the waterway.
- Additional equipment needed such as ballasting, winching, mooring, tugs, etc.
- Engineering is required on most additional equipment needed.
- Building a barge is very expensive and if rented, then the cost can be a minimum of $5000 a day.
- Deck load calculations considerably govern the type of barge being selected.
- Can be used for spacing between other barges.

Considerations related to move technologies

Installation of specialty equipment can significantly impact the general contractor's/owner's resources such as cranes, forklifts, etc., because of the required activities underneath the bridge and installation area.

Speed of implementing a particular move method is of concern as limited time is available with bridge replacement projects. Thus, the time frame shall be coordinated with the specialty contractor beforehand. Skidding is slower than SPMTs which are, in turn, slower than Cranes. However, detailed analysis of the work zone is required in positioning the crane and associated lifting and placing radii.

The possibility of using the same equipment for removal and installation needs to be considered. This may lead to major cost savings for the project.

Deployment of every 6 lines of SPMT requires one truck, and each truck requires $4-$5 per mile of transportation cost.

Heavy lifting crane deployment cost is proportional to the number of boom sections where each section requires one truck for transportation. Also required are load permits because of the heavier and wider sections. In this case, each truck requires $7-$8 per mile of transportation cost. Mammoet owns a few large cranes that require around 130 trucks for transportation.

Vertical move technologies, such as Climbing Jacks, require bracings for their operation. Usually, the specialty contractors try to avoid the use of bracings and such technologies to save cost. However for ABC projects, while using SPMTs, these jacks provide extra stroke for extra raising or lowering at the final position or staging area. Therefore, this aspect shall be properly communicated beforehand with the heavy lift/haul subcontractor so that they can preplan to provide sufficient bracings for this technology. For example, they can decide to use Climbing Jacks instead of specialized frames for falsework to reduce cost.

Ground surveys and geotechnical surveys are extremely important and require experienced personnel. Generally, specialty subcontractors have their own staff for these activities.

Specialty subcontractors such as Mammoet are best included during the early design phases. This will allow them to provide recommendations for the type of move method applicable for a particular project. This can save 1%-1.5% of the project cost and will ensure that all means and methods are adequately planned.

Monitoring

The following are the typical technologies used in structural monitoring during bridge moves:

- Load cells range from 5 ton (10 kips) to 750 ton (1500 kips) are used to identify the load imposed on the structure, such as due to jacks.
- Lasers are used for measuring and/or comparing distance.
- Strain gauges are used for measuring strain; thus, stresses.
- Pressure indicators are used for measuring hydraulic cylinder pressure.

Mammoet has software developed for monitoring special projects. Also, a generic software is available. Threshold for warnings can be set based on parameters indicated by the engineer or the owner.

Removal of Existing Structures

It is essential for the owner/DOT to evaluate methods for removing/demolishing existing structures. Major cost incurred to heavy lifting/moving subcontractors is mobilization and demobilization. Using the same heavy lifting equipment for removal of an existing structure and placing a new structure will lead to cost savings. In addition, it is necessary to identify the extent of deterioration of structural members, weight and center of gravity of the existing structure before implementing any move technology for removal. Cost savings can be realized when the structure is lowered to a manageable height for demolition.

Extreme consideration must be given for prediction capabilities while using explosives for demolition. Alternatives to using explosives must be investigated, such as cutting the structure and moving for safe demolition.

Procuring ABC Lifting and Transportation Solution

"Procuring any lift and transport solution is not about how to get the cheapest solution; it is about how your procurement will fit best in the entire project." Lifting and transportation costs can account up to 2%-3% of the project cost. Proper communication is needed between the DOT and the heavy lift/move subcontractor about the potential means and methods. The owner's/DOT's plans on the *"procurement"* aspect at the inception of the project will define clear expectations. The engineer can define the need for bracing, falsework, lifting and loading points. In addition, involving the heavy lift/move subcontractor early in the design phase will be beneficial. From the specialty subcontractor's perspective, the overall project cost will increase without using modern technology or transportation methods.

Savings of up to 20% to 30% of specialty subcontractor's contract value can be achieved by implementing the following practices:

- Reviewing method of lift and/or transport by specialized engineers
- Designing support and lifting points during the early stages of engineering

- Constructing the structure as low to ground as possible with sufficient space for transportation or lifting access
- Combining removal and installation of structures using same equipment
- Involving lifting/ transportation contractor during the design phase
- Providing bracings between Structure, Barges, SPMTs, Jacks, etc. Bracings are extremely crucial aspect for a structure move.

In addition to achieving the best possible cost, the following need to be avoided:

- Adding extra weight at the last moment. This requires bringing extra equipment, engineering staff, etc.
- Falsework such as containers for staging area: The containers need to be tested, certified, and approved by the lifting contractor.
- Custom made rigging, towers, etc. This is because the construction work as well as activities for moving operations are performed around these structures, and thus, requires engineering.
- Extreme deadlines. These may lead to extra labor cost, especially if the deadlines are communicated very late to the specialty subcontractor.

To ensure good quality of the project the following practices shall be ensured:

- Education and experience needs to be documented for all employees involved in preparation and execution of the project such as, training, testing, certification of employees, etc.
- Safety shall not be reactive but pro-active in terms of training, pre-employment and random drug screening, kick off, toolbox, and lessons learned meetings.
- Having a good contingency plan that takes into consideration aspects such as, equipment maintenance and repairs according to guidelines of manufacturers, spare part management, documentation and certification
- Communications during entire project through available and clear lines: Appropriate engineers shall be communicating with each other and following up regularly during the entire project duration.

BRENT ARCHIBALD, DELCAN INC., CANADA

Delcan Inc. is a Canadian design and consulting firm with its head office in Toronto, Ontario. Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

Ontario is slowly starting to adapt the ABC blueprint from its neighbors. The main driver for ABC in Ontario has predominantly been durability and quality control issues with cast-in-place projects. This led to a wide use of precast components with field cast joints using ultra-high performance concrete. The Ontario Ministry of Transportation had performed a handful of accelerated replacement projects, but still they are trying to figure out how ABC fits in with their program.

In Canada, bridge sliding is not a new initiative. On Oct 20, 1957 a 3000 t (3306.93 ton or 6613.87 kips) truss was laterally slid into position when the bridge clearance was increased over the St. Lawrence Seaway in Montreal, Quebec. This project illustrates that even without ABC initiatives the construction industry has been greatly involved in bringing forth these ideas to fruition and demonstrating the economic benefits.

Three slide-in project details will be discussed. The projects are:

- Dundas Street Bridge (lateral slide),
- Don Valley Parkway Underpass (jacking and mining), and
- West Toronto Diamond (lateral slide).

The major constraints that led to the implementation of slide-in technology were: (1) maintenance of traffic, (2) maintenance of utilities, and (3) interference of existing transportation structures and buildings.

Dundas Street Bridge Project

The Dundas Street Bridge is a 3-span continuous box-girder bridge located in Trenton, Ontario. The bridge is 600 ft long and weighs 3000 t (3306.93 ton or 6613.87 kips). Interestingly, the weight of Dundas Street Bridge was same as the truss weight that was laterally slid during the St. Lawrence Seaway project in 1957. Additionally, the inspiration to perform a lateral slide for Dundas Street Bridge project was taken from

Qauibrucke Bridge in Switzerland. For the Qauibrucke Bridge project, a 4000 t (4409 ton or 8818.5 kips) multi-span new bridge was constructed adjacent to existing 3800 t (4189 ton or 8377.6 kips) bridge, and both bridges were slid together in a 54 hour slide-in operation in 1984. The bridge deck carried traffic lanes as well as light rail tracks. The Qauibrucke Bridge was constructed by VSL Heavy Lifting Inc., who was involved in the sliding of several major and complex structures in Europe. Therefore, Delcan Inc. developed a relationship with VSL Heavy Lifting Inc., to understand detail aspects of a slide-in process to be applied on Dundas Street Bridge.

In 1990, the Dundas Street Bridge was slid laterally 10 m (33 ft) in 4 hour slide-in operation. This was the first lateral slide of a multi-span bridge in North America. It was completed as a conventional design-bid-build project, and the details for slide-in were included in the contract documents. VSL Heavy Lifting Inc. was identified as the preapproved slide-in sub-contractor to be retained by the general contractor. The total duration of the roadway closure was 8 days. The project reduced social costs as well as business losses inherent with conventional staged construction.

The new bridge was built adjacent to the existing bridge while maintaining traffic on the old bridge. Once the new bridge construction was complete, the traffic was diverted on to the new bridge. Then the old bridge was demolished and removed. Afterwards, the substructures and jacking paths were constructed for the original alignment of the bridge. Finally, the bridge was laterally slid into its final position.

The bridge, being 3-span, was slid using 4 jacking tracks on each line of support (2 on piers and 2 on abutments). The abutments utilized a single strand jack arrangement, and the piers utilized double strand jack arrangement. This was because of the extra load at the mid-span. A central computer control station was set up on the mid-span of the structure to allow for single point control of the jacking operations. The jacks used for the operation were double-acting plunger type jacks capable of developing a safe load of 70 t (77.16 ton or 154.32 kips).

Each slide-in unit consisted of a structural steel track beam supported on the RC substructure (fully closed bents or piers). A series of Teflon laminated neoprene steel reinforced pads were set on the steel track beams with the Teflon facing upwards. Welded steel carriages with stainless steel bottoms were placed on top of the Teflon pads. The permanent bearings of the bridge were laid on the welded steel carriages, and the bridge was slid along with the carriages. Typical pot bearings were used, and there were provisions for locking up the bearings and for providing lateral restrain to the structure during the slide-in operation. The bridge was slid at an average rate of 2.4 m (7.87 ft) per hour. The slide-in movement was monitored using CCTV cameras. There were scales attached on the slide path to notify the operator about the progress of side-in movement. The friction that was observed during the slide-in operation was 1-2%; this was when the bridge was in continuous movement. Synchronous control of the hydraulic system by computer was implemented to shut down the system automatically if any element malfunctioned or if displacements between the substructures exceeded the allowable limit. The system was also programmed to stop every 20 mm (0.79 in.) of sliding for checking. In addition, short stroke pushing jacks were used in combination with pulling jacks to overcome the initial braking friction.

Once the bridge was in its final position, the substructure was completed and the slide path was encased in concrete leaving the permanent bearings exposed. In the meantime, expansion joints were installed, concrete backwalls were cast, and the roadway transition was completed. The total duration for all the aforementioned work was around 8 days.

Don Valley Parkway (DVP) Underpass Project

The DVP underpass consisted of a new arch tunnel through an existing railroad embankment. Delcan proposed the unique method of jacking and mining to advance the structure underneath the railroad. The inspiration for DVP underpass project was acquired from other projects performed by Cementation Inc., a United Kingdom based Construction Company. Cementation Inc, was heavily involved with jacking and mining short tunnels through embankments. Another inspiring project at that time was the Bochum underpass project located in Germany. This project was a twin cell concrete box structure, which was encased in a concrete shield and jacked under 5 electrified railway lines using the jacking and mining operation. Three slide paths were utilized under the main structural walls of the structure. At the final position, the structure had 3-4 m (9.84-13.12 ft) of overburden of the embankment.

The DVP underpass project was a single cell tunnel structure weighing approximately 2000 t (2204.62 ton or 4409.25 kips). The project was located immediately adjacent to a major expressway and underneath a railroad in Toronto, Ontario. In 1989, the structure was successfully jacked 30 m (98 ft) into its final position. The jacking and mining were simultaneous operations. The jacking and mining operation took 11 days. The project was successful in terms of minimizing impact to the railroad operation and preventing settlement of the railway tracks. In addition, the expressway traffic and the existing adjacent expressway tunnels were not impacted. The project was completed 6 months ahead of schedule. This project introduced the simultaneous jacking and mining technology to North America for sliding bridges.

The single cell tunnel structure was constructed adjacent to the embankment. The embankment was cut as much as possible to minimize the jacking and mining operation. A railroad protection headwall was installed at the starting location of the jacking and mining operation. The tunnel structure consisted of a steel cutting shield at the front and two arch units: a leading unit and a trailing unit. There was an intermediate jacking station located in between those two arch units. The intermediate jacking allowed for the jacking to proceed without requiring excessive jacking forces and also enabled steering of the structure during the operation. The structure was constructed on a thrust base that was the main reactionary element used to advance the structure. Plastic sheeting between the thrust base and tunnel was provided to reduce the sliding friction. A jacking frame was used for advancing the tunnel using the reactionary force from the thrust base. The jacking frame was advanced along the thrust base in increments as the tunnel was advanced. A total of 4000 t (4409.25 ton or 8818.5 kips) of jacking force was applied to the jacking frame.

Rubber sheeting was provided on the roof of the excavated portion of soil and was advanced as the excavation and tunnel sliding progressed. This was to allow interaction between the rubber and concrete, which generates less frictional forces compared to soil-concrete interaction. In addition, the top surface of the tunnel was painted with high gloss paint, and other materials were injected to minimize the sliding friction.

Once the structure was at its final position, the steel cutting shield was removed and a cast-in-place concrete section was added to the front of the tunnel.

The construction sequence included the following:

- Install struts supporting the railroad protection headwall.
- Construct the thrust base.
- Install plastic sheeting between the thrust base and tunnel.
- Cast the tunnel.
- Integrate the steel cutting shield into the tunnel.
- Complete structure in pre-slide position.
- Install the intermediate jacking station.
- Install the jacking frame.
- Advance the tunnel combining the mining operation.

It is important to note that not every project requiring a roadway tunnel under a railroad can be performed using slide-in technology. For example, the Dufferin Underpass in downtown Toronto, after several attempts in planning for slide-in operation, was deemed to be very complex. Hence, the underpass was constructed using conventional staged construction. The structure was a two-cell tunnel structure that was expected to be connected to a T-intersection to make Dufferin Street a continuous roadway, where a railroad with 8 tracks was passing over. The structure could have slid under the railway tracks. The limiting constraint was getting the structure to ultimately carry the existing bridges at the end of the embankment. This was deemed to be risky due to insufficient geometric control.

West Toronto Diamond Project

The project site is one of the busiest railway intersections in Canada, and it is located within one of the oldest parts of the city. The project consisted of separating a railway freight corridor from a public transit railroad. The project consisted of 4 prestressed slab bridges that were post-tensioned together to form a large slab structure. Two bridges (NOTO) were 1800 t (1984.16 ton or 3968.32 kips) each, and the other two bridges (OWR) were 4500 t (4960.40 ton or 9920.08 kips) each. This site was identified as a suitable candidate for slide-in after evaluating site constraints. The NOTO bridges needed to be slid 28 m (92 ft) with 24 hr track possession (on a long weekend), and the OWR bridges needed to be slid 80 m (262 ft) with 40 hr track possession. One of NOTO bridges and one of OWR bridges were moved in 2013, and the remaining bridges are scheduled for 2014. The NOTO bridge was slid in to its final position in 2 hours while the OWR bridge was slid in 6 hours. These projects were successful in terms of minimizing the interference with rail traffic, and eliminating the need for track diversion and railway infrastructure/ property relocation.

Early on in the project, Delcan Inc. had discussions with VSL Heavy Lifting Inc., regarding the material and technology that shall be implemented for the project. Based on the experience and lessons learned from the Dundas Street Bridge project, Delcan realized that one of the key issues that needed to be addressed was to implement a system that allows moving the bridges within the permissible time frame of the railway. Thus, a system was required with fast sliding operation and minimal work required afterwards for fixing the bridge in its final position. A feasible solution was to implement a continuous sliding operation using Tandem jacks that provide an estimated rate of 20 m (65 ft) per hour, compared to conventional single jack that provides a rate of 10-12 m (33-40 ft) per hour. The central jacking operation control unit incorporated modern technology. HSL strand jacks of 200 t capacity (220.5 ton or 440.9 kips) were used with the Smart Cylinder control program allowing overload limits and synchronization parameters. Each jack had linear encounter allowing a computer to adjust the cylinders in real time and keep the distance travelled uniform regardless of differences in load in each jack. A millimeter level tolerance is specified by the strand jack manufacturer. However, this tolerance limit was not achievable at all stages of the project because of the strand/tendon release effect that initially overcomes the braking friction. Overall, the jacking was simpler than the Dundas Street Bridge project, because the slabs were simply supported and stiffer.

In addition, to prevent subsequent jacking forces (pushing and pulling) and any immediate work on slide path after the slide, the path was incorporated on top of a permanent wall and permanent bearings were incorporated in the sliding surface. The sliding surface comprised of bronze on steel with an estimated braking friction of 15% (i.e., static) and sliding friction of 8% (i.e., dynamic). The bearings consisted of top and bottom steel plate and an external steel plate that had bronze surface on the other side to slide on the slide path. These materials gave a suitable friction coefficient and acceptable materials for the slide path. Two guided bearings were provided on one slide path at the front and rear ends of each structure.

The slide path consisted of a series of steel plates, each approximately 8 ft long, permanently anchored on top of the permanent wall on the post-slide location. However, on the pre-slide location, the steel plates were temporarily anchored using anchors and custom bushings to facilitate removal and reuse of the plates in other slide projects. The plates were machined to a very tight tolerance. Also, a tight tolerance was stipulated for the slide path.

An alternate sub-contractor with experience in heavy lifting was selected for the sliding operation. That contractor offered to perform a full-scale slide test of one of the bearings in order to determine the friction due to different types of lubrication. The shop trial was setup with a single jack and single bearing with an estimated superimposed weight to be carried by the steel plate. The contractor demonstrated that the friction values were lower with a greased slide surface compared to an oiled slide surface. Thus, grease was selected for lubricating the slide path.

In order to provide additional assurance to the railway, 5 m (16 ft) test slides were performed for each of the actual bridges a week ahead to the actual slide. The bridges were constructed sufficiently away to allow for these test slides. The existing railway tracks were supported on temporary structures to allow for slide path construction and tendon for sliding. The bridges were slid with the railway ballast in place to reduce the work time after slide operation. The entire slide operation was successful. Only a few corrections were required mainly at the initial startup of the slide operation.

The tendons remained stationary for the entire sliding operation. The tendons were passed through the slab, and the slab was pushed with jacks being guided and supported by the tendon. The slide-in operation was successful in limiting the overall relative displacement between the two jacking paths to 2 mm (0.079 in.). It should be noted that the slide-in operation was relatively quick and completed within 2 hrs out of 24 hrs of railroad possession. The rest of the time was attributed to removal of the temporary structures and work that were required for slide-in operation. One of the key operations that needed to be complete before the bridges were opened to traffic was to anchor the bearings following the slide operation. The slide path was provided with holes for anchoring the bearings in the final position of the bridge.

KENNETH PRICE, HNTB INC., USA

This section will provide details on sliding and launching that have a potential for implementation on a typical highway or at grade separation. Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

There is a potential for creativity in combining the construction methods/technologies such as floating, launching, sliding, jacking, and lifting, to address the contemporary challenges of mobility and constructability. In addition, there is no limit or constraint on the extent of combining those methods/technologies, and of collaborating among the owners, consultants and contractors to address the challenges.

Sliding Technology

The project discussed here is the reconstruction of Jamaica and Hillside Avenue Bridges over Van Wyck Expressway, a busy expressway leading to JFK International Airport in New York City.

The two bridges were in very close proximity to each other over Van Wyck Expressway. The bridges were slid-out and slid-in simultaneously. This project was completed few years ago and was the first slide-in-slide-out in the U.S. This project was a prototype of the slide-in technology implemented on a two-span bridge in Switzerland.

It should be noted that when a project is identified as feasible for slide-in technology implementation, and an opportunity exists to relocate the substructure, then the opportunity needs to be exercised. This will generate several benefits and prevent new substructure construction interfering with the existing bridge. However, for this project, it was impossible to relocate the substructure. Thus, to demolish the existing bent and reconstruct a new bent, temporary double bents (i.e., temporary bents on either side of existing bent) were utilized at the mid-span of the bridge. Another issue with this project was that the bridges needed to be slid-in at higher elevation and lowered to final elevation. This was because of existing utilities, extensive fiber-optic cables, and critical communication lines that could not be interrupted. Conventional Hilman Roller technology was utilized for the process.

In Europe, stainless steel and Teflon with a very low coefficient of friction are being used for sliding operations. The coefficients of friction (static and dynamic) are critical estimates as they define the required jacking hydraulics for mobilizing the structure. Sliding a multi-span structure introduces additional complications such as the structure needs to be aligned, needs to be guided, and requires more precise operation than sliding a single span structure.

Launching Technology

The incremental launching concept comes from segmental concrete industry. If a bridge project has site constraints, such as short spans and very difficult access, typically the launching technology is considered as the solution. However, this technology can be shrunk down to small scale for typical grade separation bridges including one or two span structures.

A simple cast-in-place post-tensioned structure with launching technology is ideal for reconstructing a bridge over a very busy railway that limits access to cranes, opposes interruption to railway traffic, and has high risk/safety considerations. Concrete bridges with spans up to 80 ft can be launched conveniently without a nose or with a very small launching nose and without temporary piers. However, a typical steel launching nose is required for bridges with spans over 80 ft along with temporary piers. In addition, a king post and stays are included for spans up to 210 ft. Bridges have been successfully launched up to 4500 ft (0.85 mile) in length. In these cases, the projects had extensive demands and considerations. However, when the spans get longer new challenges are introduced.

Generally, post-tensioning of the structure in the longitudinal direction is required for implementing launching technology. In addition, it is essential for the launching nose design to accommodate/limit the stresses on the structure due to the cantilever moment. The length of launching nose can be up to half-a-span; however, the launching noses can be designed very short, provided the span is designed to accommodate large deflections and accommodate an angle of curvature and deflection within limits at the landing point.

In these cases a “rocker” (i.e., a temporary bearing at pier location) can be utilized, on which the curved launching nose is landed, rolled up and rotated onto the piers.

The hydraulic jacks required for launching technology are readily available. Design of launching track, launching bearing, and hydraulics is readily available and is not required these days. Bridges with complex geometry, such as a horizontal and vertical curvature, can also be replaced using launching technology. However, the curvature needs to be circular instead of a second order parabolic shape. Implementing launching technology on spiral geometry bridges and varying-width deck bridges is also possible by using wider launch bearings.

The replacement of the Belleaire Causeway in Florida is an example of a smaller span bridge project that utilized launching technology. The bridge was basically on a sand island with a movable structure at one end and a channel at the other end. The proposed structure was at a higher elevation bridge to be built adjacent to an existing structure for minimizing interruption to traffic and simultaneously eliminating the movable structure. The owner, designer, and contractor decided to launch the end spans of the bridge. This was because at one end of the bridge, the draft that was immediately adjacent to the sand island was insufficient to accommodate barges, cranes, and workspace. The other end of the bridge was over a busy recreational area, and the existing parking facilities in that area could not be compromised for construction workspace.

A short launching nose that was one-half of the launching span was utilized. On one end of the bridge, the casting and launching bed had restricted space; thus, the contractor was limited to assembling one-half of the span at a time. A temporary pier was built at the center span. In the first stage, the launching nose with half of the structure was slid to the temporary piers using the launching jacks at the End Bent of the structure. In the second stage, the half-span structure was launched forward to the extent that the remaining half-span could be accommodated on the casting and launching bed. Then, the third stage and fourth stage followed to complete the launching process of that span.

BALA SIVAKUMAR, SHRP-02 R04, HNTB INC., USA

The Rapid Renewal Project (SHRP-02 R04) has been ongoing from last 6 years (2008-2013) and is at the concluding stage. The Strategic Highway Research Program (SHRP)-02 had four different focus areas; R04 is the renewal area that focuses on "*reducing congestion through incident reduction, management, response, and mitigation.*" This section presents the findings from that project as presented by Bala Sivakumar, the vice president of HNTB Inc. and the Principal Investigator of the R04 project. Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

The main goal of the R04 project was "*to develop standardized approaches to designing and constructing complete bridge systems that address rapid renewal needs.*" This is to address the replacement of typical highway bridges, also known as "workhorse" or "bread-and-butter" bridges. These bridges can be standardized to a point where new design may not be required for replacement. The means and methods are required to be considered for an ABC project. In ABC design, the owner considers and stipulates a majority of the means and methods that a contractor would undertake in a conventional project, such as demolition drawing, erection drawing, schematics of temporary works, etc. In a nutshell, the complete ABC process is laid out by the owner prior to bidding, including the construction process. This is the key difference between ABC and traditional CIP construction.

PBES can be classified as the foundation technology for ABC. PBES has been used for a long time, since around 1960's. The R04 project was not about to reinvent ABC; rather, it considered current impediments to the use of ABC. Then, solutions were derived to take successful technologies and make them mainstream in terms of design and replacement processes. The ABC toolkit guides the project designers in such a way that ABC design will not be different compared to designing conventional bridges in the past; however, minor differences exist and are highlighted in the report.

In this project, innovative designs were developed for replacing bridges in an accelerated manner. The initial focus was on PBES bridges, and then the project was extended to slide-in bridge projects. The project report presents all the research that was performed during the 6-year project duration. In addition, the report presents summaries of more than 200 ABC projects including the concepts in the U.S. and Europe. The project did not include SPMT as numerous documents were already available through FHWA and Utah DOT. The primary deliverable of the project is the ABC Toolkit that has been published. The toolkit includes design concepts with examples and sample specifications to guide the ABC novices to start. Using the toolkit, the designer will be able to easily complete an ABC design for a routine bridge replacement project. It shall be noted that the task of making ABC as a standard practice starts from the policy framework. The ABC toolkit appears in the task as the progress is made towards ABC implementation.

The R04 project also assembled design standards and specifications that include guideline drawings. In addition, ABC demonstration projects were completed to prove that the details presented in the toolkit are buildable. The essential components of the ABC toolkit are the following:

- ABC standard design concepts
- ABC erection concepts
- ABC design examples
- ABC design specifications (LRFD): These are recommended modifications to AASHTO LRFD so that it can better support ABC.
- ABC construction specifications: These construction specifications provide some key aspects that need to be considered while executing an ABC project.

As mentioned earlier, the focus of the toolkit is on PBES and slide-in for typical highway bridges. Another goal of the toolkit is to provide necessary resources for the owner to design ABC bridges. This provides the opportunity for the local contractors to compete on these projects and to self-perform the work to the extent possible. Every prefabricated element in the toolkit can be self-performed by a contractor with the exception of prestressed elements that require a certified precaster. The elements are simple to fabricate and easy to erect using conventional equipment. Some of the durable connection details are also included in the toolkit. All the details in the toolkit are meant for bridges that can be built over a weekend or no more than 1 to 2 weeks.

The toolkit includes conceptual drawings for the following PBES:

- Decked steel girders: Nonproprietary details, that a contractor can self-perform and use UHPC or rapid-set mix for connections.
- Decked concrete girders: Prestressed deck bulb-tee and double-tee (NEXT beam) modules.
- Abutments and wingwalls: Semi integral abutments, integral abutments, wingwalls, pile foundations, and spread footings.
- Piers: Precast conventional pier, precast straddle bent, drilled shaft and spread footing options.

It is important to note that the substructure construction takes the longest duration in ABC projects. Use of prefabricated substructure elements is an important part in ABC. However, the weight of precast substructure elements possesses shipping and handling challenges. Other time consuming activities include installing bearings and expansion joints. Eliminating bearings and approach joints from a bridge construction project can provide a better, more durable, and faster bridge. The semi-integral or integral bridges allow eliminating the bearings partially or completely, respectively. Using these abutments and piers, a bridge can be built in a day by eliminating extra (half-a-day or more) work required for installing bearings and approach joints.

With a semi-integral abutment, a suspended backwall is used to provide excellent fit-out tolerances in a very short duration. However, elastomeric bearings are required to allow for backwall movement to accommodate expansion. The abutment pile cap is essentially placed on top of the H-piles and filled with self-consolidating concrete. The integral abutment does not require bearing, but a grout pad is placed on dowels and grouted. In this case, the approach slab is supported on the backwall and requires a joint. It is preferred to move that joint to the end of the approach slab (i.e., at the sleeper slab location) so that all joints are moved away from the bridge. Approach slabs that are supported on ground require long construction time. Precasting the approach slabs and sliding them with the main-span can accelerate the construction.

For piers, there are two concepts: (i) conventional pier with cantilever bent cap, and (ii) straddle bent. The straddle bents are preferred because new bridges are commonly wider than the old bridges, and straddle bents allow using drilled-shafts/piles and constructing foundations outside the footprint of existing bridge.

The research decided that all superstructures considered in the toolkit will be designed simple spans for dead load, continuous for live load, and without open joints. The project investigated simple/ continuous span from 40 ft to 130 ft and grouped the plans in the span ranges of: (i) 40 ft to 70 ft, (ii) 70 ft to 100 ft, and (iii) 100 ft to 130 ft. The designs were standardized within these groups. The elements within these span ranges weighed less than 200 kips and were able to be conveniently shipped and erected in one piece using conventional equipment. The weight of 200 kips was identified as the optimal for shipping and handling/erecting with conventional equipment. If 200 kips weight limit is exceeded, then the contractors need to deploy heavy lifting equipment; also, shipping the component becomes challenging requiring permits. This will drastically increase the cost.

A challenge for most designers is to design the erection concepts for PBES. To overcome this challenge, the designer should understand the site and contractor's capabilities. This requires sufficient planning time to evaluate the site and communicate with the contractors beforehand. The toolkit provides erection drawings (detailed erection plans) for the contractor to erect the PBES using conventional cranes. In addition, guidance is provided if the erection requires technologies adapted from long span construction. The toolkit also provides different crane placement and erection scenarios for typical bridge projects. It is essential to be familiar with different types of cranes available for ABC. This helps selecting an appropriate crane for erection based on the site conditions.

"The designer earns his money by thinking through the constructability of the bridge, not the design that is already available." The toolkit provides constructability analysis considering conventional crane based erection. The factors that are considered during the analysis are: (1) weight of a prefabricated element, (2) pick radius, (3) crane set up

locations, (4) ground access/ barge/ causeway/ work trestle, and (5) truck access for delivery. The constructability analysis is recommended to be performed by laying out the site plan including all the crane locations and access options. This leads to the ABC cost estimation and schedule, as the owner already decided the means and methods for the project. These aspects of ABC are very time consuming and need to be considered during the design phase.

In most cases, construction from below (ground) is expensive and time consuming. This difficulty arises in projects dealing with interstate expressways or railroads as the feature intersected. Thus, to address this issue, the toolkit considered the following ABC technologies that allow construction from above:

- Above deck driven carriers: These are beneficial on sites with limited ROW. However, they are cost effective for bridges with 10 to 15 spans but not for bridges with 1 or 2 spans.
- Launched temporary bridge (LTB): These are beneficial in environmentally sensitive areas or any restricted area that prevents a crane to be placed on the ground. The LTBs increase the possibility of erecting longer spans. They are launched across or lifted over a span to act as a temporary bridge and can be used to deliver heavy prefabricated elements without inducing large erection stresses. The temporary bridge can also support transverse gantry frames.
- Transverse gantry frames: This includes gantry girders on either sides of the bridge and on which the gantry moves. The gantry then moves back and forth to pick the old span out and install the new span.
- Longitudinal gantry frames: This includes two SPMTs with a long longitudinal gantry truss that lifts the old span and moves it out, and the new span is moved in and installed in a sequence. The gantry carries two spans at the same time.
- Regular cranes with sufficient reach.

In ABC, three designs need to be prepared for a bridge project: one is final bridge design in its final alignment/construction (similar to conventional bridge); the second design is when the bridge is being fabricated; and the third design is when the bridge is being lifted and erected in place. Each of the designs have different loading and stress requirements.

Most of the time, the governing design may not be the final bridge design but the design including lifting and erection conditions.

The toolkit provides sample drawings for ABC. The drawings show typical level of detail. The plan sheets contain ABC specific details for routine bridges. These drawings guide a novice ABC designer on appropriate module configurations, connections, and erection. It should be noted that the engineer of record (EOR) is the designer not the ABC toolkit. The EOR can take guideline drawings from the toolkit and perform his/her own design and make sure that it is adequate for a particular bridge. Limit states shall be considered in the design for the following stages: (1) prefabrication process, (2) shipping process, (3) erection process, and (4) final as-built state of the bridge.

In ABC, the lowest bid is not a goal. Saving cost by avoiding stringers, etc., is not a good design. Rather the design focus needs to be achieving an optimal configuration, with both size and weight, suitable for shipping and erection. Designing a configuration suitable for prefabrication, shipping, and erection processes will provide a best bid in ABC.

In prestressed concrete design, the release is usually checked. In ABC, additional checks are required for stresses/deflections during shipping and handling. This is because heavier and longer girders are considered. In addition, camber and deflections need to be checked at release, erection, and final as-built state. The design needs to specify the time duration the girders are allowed to be in the staging area or prefabrication yard before erecting. Also, the schedule for fabrication, curing, and transporting the elements needs to be specified.

The recommended LRFD specifications for ABC are the following:

- Loads and load combinations
- Construction load cases and erection stresses
- Design of connections
- Design responsibility – EOR/ Contractor’s engineer
- Prefabrication tolerances, quality, and rideability
- Assembly plans.

Geometry and tolerances are a high priority in PBES design in the toolkit. The loads specified for the ABC design are the following:

- Loads associated with support conditions during fabrication that may be different than permanent supports
- Loads associated with member orientation during prefabrication
- Loads associated with suggested lift points
- Load associated with impact considerations for shipping and handling of components
- Loads associated with camber leveling.

It is important to indicate that the prefabricator should not assume that the designer has all the responsibility for specifying the tolerances and camber. The prefabricator needs to work with the designer to achieve the proper tolerances and camber. This is the key issue while dealing with PBES, especially on prestressed elements. In ABC projects, the DOT needs to enforce the requirement for the prefabricator that the designer and prefabricator shall work together to achieve proper tolerances and camber.

The design examples in the toolkit are organized in the following sections:

- General
  - Design philosophy
  - Design criteria
  - Material properties
  - Load combinations
- Girder design
  - Flexural strength checks
  - Flexural service checks
  - Shear strength
  - Fatigue limit states
- Deck design
  - Flexural strength check
  - Deck reinforcing design
  - Deck overhang design

- Continuity design
    - Compression splice
    - Closure pours design

The following special PBES construction specifications sections are recommended for LRFD in the toolkit:

- General
- Responsibilities: This deals with handling the responsibility for the system that gets designed in multiple arenas such as design office, contractor's engineer office, specialty contractor office.
- Materials
- Fabrication: In ABC, bridges are being built partly on-site and partly on a precast facility; thus, the fabrication and inspection are responsibilities divided to those locations.
- Submittals: There are several submittals required based on the ABC technologies compared to conventional construction.
- Quality assurance: This needs to be ensured that the prefabricated elements are assembled in a manner to achieve quality standards of the final product equal to individual elements.
- Handling, storing, and transportation
- Geometry control: This is the key issue in the assembly process. Different tolerance requirements for various PBES are to be considered based upon their respective role in a bridge.
- Connections
- Erection methods
- Erection procedures.

Two demonstration projects were implemented using the toolkit. The first was a PBES, the Keg Creek Bridge project in Iowa. In 2011, the bridge replacement was completed within a 14-day ABC closure period. MOT and user costs justified ABC at this site that required a detour of about 14 miles and a conventional design of 6 months closure period.

The PBE of this 3-span bridge were fabricated on-site by the contractor. The on-site fabrication saved approximately $0.5 M compared to outsourcing the prefabrication. UHPC closure pours and precast approach slabs were used in the project.

The second demonstration project was a slide-in construction, NY I-84 Bridge project, in New York. The bridge replacement was completed within a 20 hr ABC closure period. The old 3-span bridge was converted to a simple span as the new bridge. This project used the lateral slide technology combined with Utah DOT method of sliding in with the approaches. The approaches were supported on an inverted-T as sleeper slabs. This process was utilized as the interstate alignment needed to be raised by 2 ft overnight. The demolition and sliding was performed in a 7-hr duration. The remaining time (around 12 hr) was required for raising the approaches by 2 ft layer-by-layer. Even though this was a slide-in project, PBES was used to fabricate the new superstructure from the toolkit details, such as NEXT beams, precast approach slabs, and UHPC connections.

The toolkit also includes a one-day course on ABC. The course is a set of slides to familiarize the engineer/ participant with ABC in general and the ABC toolkit.

REBECCA NIX, BRIDGE PROGRAM MANAGER, UTAH DOT

Utah DOT has been working with their ABC program since 1999. At that time, the Utah highway system did not have very many bridges that were structurally deficient. However, bridges were aging, and one-third of the bridges required replacement in the next 30 years. Thus, ABC provided an efficient technique to replace their structures without making major impacts to the travelling public.

This section presents the Utah DOT's ABC implementation plan, different contracting methods for ABC projects, contract documents, monitoring plans, and contingency plans. This section also provides a comparison among SPMT and lateral slide, and lessons learned. Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

Utah DOT's ABC Implementation Plan

Utah DOT's ABC implementation history includes: (1) Half-depth deck panels project in 1999, (2) Full-depth deck panels project in 2004, (3) Precast substructures project in 2007, (4) SPMT project in 2007, (5) Lateral slide project in 2009, and (6) Superstructure launch project in 2010.

In addition, Utah DOT implemented their first lateral slide project involving a geo-synthetic reinforced substructure in 2013. This project was over a river, and the superstructure and substructure were slid together in a single move. The structure was pulled into place using winches and a pulley system. Here the superstructure was slid via MSE wall (acting as substructure) placed on rolling tracks. Later, the structure was tied directly to the roadway approaches to develop one continuous system. The approach slabs were cast-in-place; thus a little longer closure period was required. A week later, Utah DOT implemented a second lateral slide project that utilized precast approach slabs that reduced the closure period.

Utah DOT considers the following benefits of implementing an ABC project:

- Enhanced safety
- Shortened on-site construction time

- Reduced traffic/ mobility impacts
- Potentially reduced project costs: Initially these were in terms of reduced MOT cost and user delay cost. Afterwards, the overall project costs were brought down using the economy of scale concept.
- Improved quality: The concrete superstructure components are wet cured for the full duration in staging area. This allows achieving improved concrete quality in comparison to traditional construction that limits wet curing duration because of lane rental penalties.
- Improved constructability: The constructability is improved as the workers are in a safer zone outside traffic. Also, a full-lap splice between a closure joint as in case of staged construction is not needed.

Contracting Methods for ABC Projects

The traditional contracting method of design-bid-build is used for some of the ABC projects in Utah. However, this does not allow contractor involvement during the planning and design phases of the project. This generates a higher level of risk to the owner. Also, a higher amount of change orders were documented on design-bid-build ABC projects. Thus, while dealing with ABC projects, Utah DOT decided to have a strong team partnering and coordinating with the DOT, the designer, and the contractor.

The design-build is another contracting method that Utah DOT uses for ABC projects. Through such a process, the DOT is able to contract about 30% of the design phase with a consultant and contractor team. As a result, the team is able to perform the design and construction in phases. (While the first design phase is completed and the second design phase starts, the construction of the completed design [first phase] is started.) However, a higher bidding effort, upfront in the project, is required for the contractors. Utah DOT has a short list of contractors; whenever Utah DOT requests an initial design from the contractors, it provides a stipend. This was because, at that stage, the contractor was only at 30% design and had several variables to consider in future phases of the design. The benefits of design-build method compared to design-bid-build method are the following:

- Concurrent design and construction

- Early known cost: This is because the project is bid on type of work rather than individual items.
- Reduction in delivery time
- Improvements to constructability
- Encourage innovation
- Risk is transferred to contractor.

The third contracting method is the Construction-Manager – General-Contractor (CMGC) method. This method is used mostly on slide-in projects. The project plan is developed by the owner. Afterwards, the design team, including a contractor, is allowed to be on board to provide input throughout the project. The contractor on board is able to identify and mitigate risks upfront in the project. This provides a path for innovations and agreement among the owner, the designer, and the contractor. Other benefits of this contracting method include reduced design errors, constructability issues and change orders, and it allows for early procurement for long lead-time items. The method also limits negotiation on project costs because the owner (DOT) understands the rationale behind the contractor's pricing. After design, an independent cost estimate is performed in-house and compared with the contractor's estimate. Utah DOT has set a limit that if the contractor's estimate exceeds the estimate by a defined percentage, then the DOT has an option to convert to traditional bidding. The DOT in this case is not limited to the contractor in the design team.

Contract Documents

There are three levels of contract documents in Utah. The options are the following:

- No detail regarding the ABC method used: In this case, the plans are provided by the DOT similar to CIP structure; the contractor can decide on the mobilization method and develop any associated details. This was mostly useful for design-build projects.
- Show one viable option, schematic: In this case, the DOT will choose and provide one viable method for mobilization of the structure, but it will not provide

the process of mobilization and associated details to the contractor. This was mostly helpful for design-bid-build projects.

- Show permissible move details: In this case, the DOT will provide the viable method of mobilization along with associated details. The documents in this case are detailed. This was mostly helpful for CMGC projects.

In the contract documents, it is essential to define the goals, limitations, and requirements of the project. The specifications shall include the following:

- Submittal requirements: Design and other associated details such as temporary support details, etc; level of design and details that the contractor is responsible for
- Contractor flexibility: Limiting to one prescribed method and associated details or allowing the contractor to select a method
- Tolerance requirements: Tolerance requirements are relaxed a bit compared to conventional construction. However, the contractor needs to identify and understand the precision required when the bridge is brought to its final location.
- MOT requirements: This is the critical requirement that the contractor needs to understand and focus on. Utah DOT allowed the contractors on several projects for lane closures, on feature intersected, a day before the SPMT move in order to demolish one lane of the bridge. In addition, the contractors were allowed to move the bridges half-way, a day before the move; allowing them to check their systems during daylight hours.
- Incentives and Disincentives: Several projects in Utah were awarded incentives when the roadway was opened to traffic ahead of schedule. However, disincentives incurred in some projects in Utah because of delays in roadway opening. Utah DOT has a *tier* system for penalties, wherein the first couple of hours a lower disincentive is imposed to assure quality of the structure. After 2-4 hours beyond the schedule, higher disincentives are imposed.

In the contract documents, it is essential to allow for a review time in the schedule. In addition, based on the level of detail, the design team and the contractor are to be notified about the level of effort required in regards to the following submittal items (so that their respective schedules could be customized):

- Changes to contract plans
- Temporary supports including geotechnical evaluation
- Staging areas
- Hour-by-hour schedule
- Communication plan
- Contingency plan.

SPMT vs. Lateral Slide

Utah does not have SPMT locally available, so it is difficult to get SPMTs mobilized. Thus, Utah DOT selected larger projects with 7-8 bridges that needed replacement at the same time for the SPMT move. However, for lateral slides, Utah DOT used basic equipment such as tracks, rollers, and hydraulic jacks. They used post-tensioning jacks to serve the purpose of hydraulic jacks during the slide. The equipment was cheaper and lowered the project cost significantly for slide projects. The following table summarizes the comparison among SPMT and Lateral Slide:

SPMT	Lateral Slide
Equipment cost is high	Equipment cost is low
Staging area location is flexible	Staging area needs to be adjacent to the structure
Feature intersected is less critical and is least impacted	Feature intersected is impacted
Pick points of the structure vary from final supports	The structure is slid using the same support locations as the final supports

Monitoring

In Utah, monitoring is kept simple and basic for all the moves. Usually, surveys are performed to check the levels, string lines, and measuring gaps. However, measuring deflections is not required other than basically ensuring that the bridge is not twisted. For example, in a lateral slide project, a chalk line was drawn on the abutment and diaphragm and tracked down during the slide.

In a lateral slide project where the superstructure was slid with the approach slab, frequent measurements were taken throughout the move to maintain the required gap between the sleeper slab and the end of approach slab. This measurement was helpful to ensure a consistent gap on either side of the bridge and identify any twisting of the bridge.

Contingency Plan

The contingency plan ensures that the hour-by-hour schedule is observed. This provides an interpretation of the move or slide progress and allows mitigating any issues promptly. In addition, public involvement needs to be coordinated well, and a couple of hours of contingency (beyond the contractor's proposed time) must be reserved in the project closure time that is advertised to the public.

There should be a contingency plan for means to back up the bridge, if necessary in cases when the bridge is moved-in at an inappropriate angle and/or is rubbing on the substructure. In addition, there should be plan/ability to adjust the bridge alignment, if necessary in cases such as the structure is very close to one abutment compared to other abutment.

Also, it is essential to have spare equipment and/or parts in stock on-site, for crucial equipment such as spare jacks, spare control units for SPMTs, and common failing parts.

Lessons Learned

The following are the lessons learned from the SPMT projects in Utah:

- The contractor should not reuse any beams from a demolished bridge to function as carrier beams for SPMT move.
- Survey is very crucial.
- The project team needs to account for all utilities in travel path.
- Specifications need to clearly outline the expectations.
- The project team needs to account for varying load paths.
- The project team needs to provide adequate roadway tie-in lengths. This issue came up multiple times in Utah. Utah DOT was trying to limit the tie-in lengths

as much as possible for limiting the amount of fill and asphalt that needed to be placed during the night. However, full-size equipment was not able to accommodate the limited excavations which ended up extending the tie-in lengths.

The following are the lessons learned from the lateral slide projects in Utah:

- Slide-in technology needs to be specified following several investigations of the site constraints.
- The project team must account for interaction between temporary and permanent supports. Utah had one slide project where the temporary structure settled at the connection point with the permanent substructure. Additional supports were installed to the temporary structure to obtain appropriate transition to the permanent substructure.
- The project team needs to consider moving approach slabs with the superstructure. In this case, the approach slabs are constructed and slid along with the superstructure. Here an inverted-T shaped sleeper slab is placed at the approach slab ending location prior to slide. The approach slab slides on that sleeper slab and the end diaphragms slide on the abutment. A flowable fill is placed underneath the approach slab. This process eliminated the time required for compacting approach soil and constructing approach slabs. The approach slabs are designed for their full span to ensure proper support in case the fill underneath undergoes settlement.
- The project team needs to provide adequate roadway tie-in lengths.

HALUK AKTAN, PROFESSOR, WESTERN MICHIGAN UNIVERSITY

This section provides an overview of "alternative analysis for project delivery." This relates to the decision-making framework and analysis tools that are currently being developed under MDOT's research project at Western Michigan University. Dr. Haluk Aktan is the Principal Investigator of the research project. The specifics of the framework and tool were developed with input from MDOT research advisory panel (RAP) and the project manager, David Juntunen. Please use the presentation slides given in Appendix D while reviewing the information presented in this section.

Several project delivery options are currently available, conventional construction (CC), ABC – PBES assembling, ABC – SPMT move, and ABC – Bridge Slide. The analysis is required to identify the most suitable project delivery method for a specific site.

Currently, DOTs use different procedures and methods in performing the alternative analysis. These are flowcharts, structured binary tables, scoring models, and analytical hierarchy process (AHP). The primary requirement for the alternative analysis framework and the tool is to provide an intuitive and a robust analysis tool. Specific criteria are the following:

- Comparisons should incorporate project-specific quantitative data.
- Analysis should include life-cycle cost (LCC) data and user cost (UC) models.
- The tool should allow collaborative input from multiple experts for the decision-making.
- The tool should have automation to improve usability and efficiency of the decision-making process along with addressing the sensitivity of results.
- The method used should have mathematical validity.

Considering the LCC and UC models, there are several models of various complexities available. Considering the parameters related to the LCC and UC models, some are very simplistic and some are overly complex. Therefore, when these models are adapted to ABC, only essential parameters are considered and applicable models for those parameters are selected.

The software being developed in the research project is called the Michigan Accelerated Bridge Construction Decision-Making (Mi-ABCD) model. It is guided software for the users. The software uses the Analytical Hierarchy Process (AHP) that can be used in any comparison problem. The model requires defining the major- and sub-parameters that control the problem. Then pair-wise comparisons are performed for the following on a scale of 1 to 9: (i) among the major-parameters, (ii) among the sub-parameters related to each major-parameter, and (iii) among the construction alternatives with respect to each sub-parameter. Afterwards, AHP matrices are developed and priority vectors are calculated. Finally, the preference probabilities for the decision alternatives are calculated.

In the software, the major-parameters considered are: (i) Site and structure considerations, (ii) Cost, (iii) Technical feasibility and risk, (iv) Work zone mobility, (v) Environmental considerations, and (vi) Seasonal constraints and project schedule, along with 28 sub-parameters. The sub-parameters are categorized into quantitative and qualitative sub-parameters. The important aspect to consider is to decide on the process of obtaining the user data including quantitative and qualitative data for sub-parameters. Thus a Graphical User Interface (GUI) was developed to allow the users to enter data, and behind-the-scene is the mathematics that performs the calculations and outputs the preference probabilities for the decision alternatives.

The software is developed using Microsoft Excel and Visual Basic for Application (VBA) scripts. The VBA's GUI allows interaction with the users. It includes the following:

- Pop-up menus
- Datasheets
- VBA scripts
- Embedded worksheets.

One important aspect in the software is the requirement for two levels of users. It has *Advanced User* and *Basic User* modules. The *Advanced User* is considered as the project manager or any project personnel who has knowledge on the majority of the quantitative data for a project. The *Basic User(s)* are the experienced engineers on the project team who can provide qualitative judgments for the project in comparison to the past projects of which they were a part.

The data entry needs to start with an *Advanced User* for a project and the data required from the *Advanced User* are the following:

- Project details
- Site-specific data
- Traffic data
- Life-cycle cost data
- Preference ratings.

Multiple *Basic Users* can enter their qualitative judgments on ordinal scale ratings under the *Preference Ratings* data entry section. The *Preference Ratings* section includes questions that the *Basic Users* answer. The answers are specific to the sub-parameters and render opinions on an ordinal scale of 1 to 9 in comparison to earlier similar projects. This is a major advancement implemented in the software compared to regular AHP pair-wise comparison. This is to eliminate the concern of comparing two unrelated parameters, such as Cost vs. Safety, as both are equally important. In addition, the users can provide comments for the *Preference Ratings* that are visible to future users and provide the perspective of previous users in regards to a corresponding sub-parameter. However, in this case, the preference ratings from the previous users are kept private for future users, and only the final analysis/evaluation results are visible. The mathematical formulation in the background develops AHP pair-wise comparison matrices based on the ordinal scale ratings.

The software has the capability to allow the advanced user to add or remove parameters. The analysis also requires *general data* that remains unchanged for a particular region/state. General data can be edited if the software is used for evaluating a project in a different region/state. These aspects of the software are accessible to the *Advanced User* only.

The results from the analysis/evaluation are displayed in three forms: (i) Pie charts that show the upper and lower bound results of user data, (ii) Line chart that shows the distribution of major-parameter user preferences, and (iii) Bar chart that shows *Preference Probabilities* of the project delivery alternatives. Also the data in the charts is displayed in a tabular format as numbers.

The software implementation was demonstrated using the Stadium Drive (I-94 BR) bridge over US 131 project in Kalamazoo County, MI. It is a sizable bridge replacement planned for construction in 2014. The analysis/evaluation was performed for CC and ABC, in particular PBES. The analysis/evaluation justified ABC for that project quantitatively. Currently, the software is capable of evaluating CC and PBES only and the extension of the research project will cover the slide-in and SPMT move technologies.

BENJAMIN BEERMAN, SENIOR STRUCTURAL ENGINEER, FHWA

This section presents an overview of the National perspective on ABC implementation. The information is presented based on the ongoing research under the *Every Day Counts (EDC)* initiative of FHWA. The following topics are highlighted in this section:

- Impact of EDC initiative on ABC and PBES delivery
- Prefabricated Bridge Elements (PBE) and Prefabricated Bridge Systems (PBS)
- Resources for implementation of ABC
- Realizations with ABC/PBES.

The EDC counts initiative was founded on three pillars: Safety, Quality, and Overall program delivery. The EDC phase-I was engaged from 2011 to 2012. In that phase, PBES technology was promoted throughout the US. The EDC program was termed as a deployment vehicle that allows collaborating in a national manner. Realizing the advancement gained from the program, another phase EDC-II was initiated in 2012 and is scheduled to end in 2014. There are 26 initiatives under the EDC-II program for shortening the project delivery; among them, the ones that impact bridges are the following:

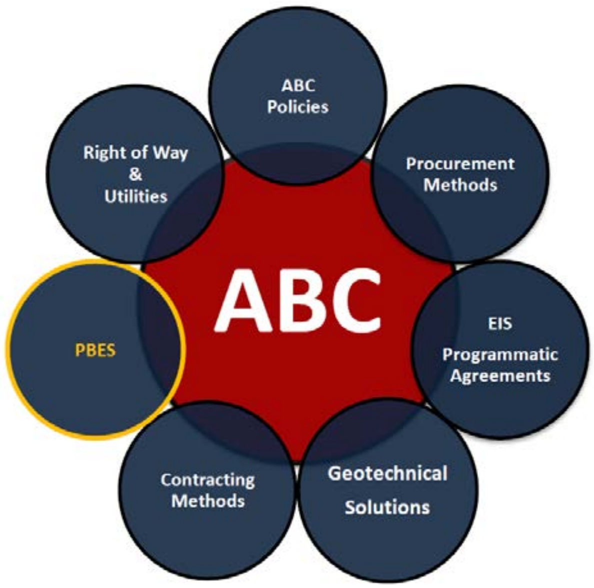
- Programmatic Agreements II
- 3D Modeling
- Accelerated Bridge Construction that includes PBES, and emphasis on GRS-IBS and Lateral Slide
- Design Build
- CMGC
- Alternative Technical Concepts (ATC).

The EDC is an opportunity that allows bridge practitioners to collaborate at national level to advance ABC innovations such as PBES into the mainstream of the bridge industry. Several deployment activities were performed under the EDC initiative specific to PBES:

- Workshops
- Webinars
- Scanning Tours

- Project Reviews
- Project Showcases
- Regional Peer Exchanges.

ABC, for a program of projects, is a combination of various strategies and technologies. The following Venn diagram explains the interaction of ABC with other aspects related to bridge construction:



Focusing on PBES, it is just a technology or strategy used to develop an ABC project or group of projects or a program of projects. The definition of PBES according to AASHTO is: "*PBES are structural components of a bridge that are built offsite, or adjacent to the alignment, and includes features that reduce the onsite construction time and mobility impact time that occurs from conventional construction methods.*" AASHTO separated the difference between the *Elements* and *Systems* to have consistent terminology. *Elements* are defined as single structural components of a bridge, such as deck elements, beam elements, deck-beam elements, full-width beam elements, pier elements, abutment and wall elements, and miscellaneous elements that include approach slab elements, etc. The *Systems* are defined as entire superstructure, entire superstructure and substructure, or a total bridge that has been moved or planned to be moved in a manner that traffic operations can resume once the structure is in its final position.

The definitions and terminology were engaged to assist in developing the National ABC/PBES Project Exchange database. The FHWA required each state DOT to submit at least 2 projects that used PBES and/or any ABC approach for the database. The database includes contract plans, specifications, bid tabs, schedule, and pictures from previous ABC projects in the US (over 100 projects available).

The National ABC/PBES Project Exchange database can be accesses using the following website:
<https://www.transportationresearch.gov/dot/fhwa/default.aspx>

Note: For accessing the ABC/PBES Project Exchange database, prior registration and site access requesting is required following the instructions presented in ABC Project Exchange User's Guide:
<http://www.abc.fiu.edu/wp-content/uploads/2013/07/ABC-User-Guide-for-posting1.pdf>

Other resources for ABC/PBES implementation are the following:

- Webinar training sessions that can be accessed from:
  http://www.fhwa.dot.gov/everydaycounts/technology/bridges/pbeswebinartraining/

- Publications that include FHWA ABC manual, Connections details for PBES, Manual for use of SPMT, etc., which can be accessed from:
  http://www.fhwa.dot.gov/bridge/prefab/pubs.cfm

- Regional Peer Exchange Meetings documents that include around 150 presentations related to ABC. The forum can be accessed from:
  <http://p2p.ara-tracker.com/

- Monthly FIU webinar series that can be accessed from:
  http://www.abc.fiu.edu/

- SHRP 2 R04 Toolkit that can be accessed from:
  http://www.fhwa.dot.gov/goshrp2/ (or) http://www.trb.org/Main/Blurbs/168046.aspx

- Other regional/DOT websites:
  http://www.pcine.org/
  http://www.udot.utah.gov/main/f?p=100:pg:0:::1:T,V:1991

In addition, to supplement the FHWA ABC manual, future publications are expected (Summer 2014) in the areas of *Planning and Policy*, *Engineering Materials*, and *Construction Contracting*.

The Transportation Research Board granted approval for the formation of ABC subcommittee under AFF10 General Structures committee. The subcommittee is named as AFF10(3) – Subcommittee for ABC, and its website can be accessed from:
https://sites.google.com/site/trbaff103/
This website is planned to contain the entire ABC related work in the US.

Recent ABC NCHRP projects in collaboration with TRB are the following:

- Development of an ABC design and construction guide specification: NCHRP 12-102
- Guidelines for tolerances of PBES and dynamic effects in large-scale bridge moves: NCHRP 12-98.

In summary, the EDC initiative enabled spreading of the "word" ABC/PBES and resulted in deployment of ABC/PBES projects in more than 46 states in the US. It resulted in paradigm shift in deployment perspective. For example, the DOTs are comparing among PBES technologies themselves, such as among pile lagging, grouted couplers, and pile pockets for abutment walls in an ABC project. In addition, the DOTs are developing standards for PBES deployment.

APPENDIX C

WORKSHOP QUESTION/ANSWER SESSION SUMMARY

QUESTION AND ANSWER SESSION SUMMARIES

Q1: Is Utah DOT still employing the same level of effort as their first few projects for public outreach and information exchange? As the public and industry may be now accustomed with ABC.

A1: For the first few projects, Utah DOT was extensively involved with public outreach. The public was allowed to view the ABC process. Now, there is no rigorous campaign to hold demonstration projects. Presently, variable message signs are used to inform the public well ahead of a project schedule. Public meetings are still held to get communities and businesses involved. Measures are taken to inform the trucking industry about a project schedule.

Q2: How does Utah DOT deal with delays in contractor's submittals for ABC projects as there is a lot more detail to be included?

A2: Utah DOT did not have many push backs from the contractors for the submittals, as the activities were planned ahead of time and were presented to contractors upfront. Also, Utah DOT was well aware of the time required for developing the documents. Hence, the entire process was scheduled accordingly. In the first few projects, the DOT allowed a 14-day review period for the contractors. After introducing an electronic submittal process, a 7-day review period was allowed. As per the lessons learned, a DOT schedule should allow for any deviations in the submittals especially when a temporary work plan, communication plan, and an hour-by-hour schedule are requested. Also, the DOT shall ensure proper communication with the contractor regarding their progress to submittals. Further, the DOT shall realize that if new contractors are providing submittals, then the submittals will differ significantly from regular contractors. Thus, the DOT schedule shall allow for additional review time from their side as well.

Q3: MDOT is looking at standardizing precast pier columns and bent caps to have standardized plans in their Bridge Design Guide. Did other DOTs do that? If so, what do they recommend for MDOT to achieve their goal?

A3: Utah DOT developed standards for precast full-depth and partial-depth deck panels. Sample standard working drawings were made available to contractors in order to give a general idea. The drawings are available through Utah DOT's website. Utah DOT also developed some specifications for ABC projects.

The SHRP 2 R04 project toolkit contains few examples for standard substructure elements. These elements were identified from various states where these elements are used in conventional construction. Contractors are familiar with the details presented by those states, but are uncomfortable in adapting those in ABC. Hence, the purpose of incorporating such elements and details into the toolkit was to provide some guidance on using such components in ABC. Thus, it is recommended that the SHRP 2 R04 toolkit details shall be used in projects after customizing according to the local practices.

There is no standardization in Ontario, Canada. Always, the Ontario Ministry of Transportation experiments with various alternatives to identify efficient and cost effective solutions. For example, the Ministry proposed precast piers for a project, and the regular contractor proposed to build conventional piers. However, the Ministry, in its administrative procedures, does not allow changes to the proposed details and procedures; thus, the contractor's proposal was rejected.

Q4: MDOT is approaching its prefabricators and showing their future path of the standardizing ABC components including substructure. But the fabricators need to make an investment on forms, etc. How does one justify this aspect?

A4: The comment from SHRP 2 R04 project team is that standardization of superstructure works very well; especially, with prestressed components. This is because the shapes are decided, and projects are available to implement those shapes. In order to promote standardized substructure elements, first, the state has to develop standardized elements and a program of projects to utilize such elements. Secondly, present the standardized elements and the details of the program of projects to the fabricators. This is a must because the fabricators need to know the extent of utilization of standard elements before investing in the formwork. However, due to variations in site conditions, it is a challenge to develop a program of projects with similar substructure elements. However, if MDOT can develop a program of projects with the aim of using similar substructure elements, the substructure elements can be standardized and the fabricators can be convinced to invest in the formwork. This is because in future of ABC the economy of scale shall control.

For prestressed elements, standardization is very beneficial as the fixed costs are higher. However, if precast reinforced concrete columns are used, columns can be prefabricated economically on-site in the staging area by eliminating the cost of transportation. SHRP 2 R04 is promoting self-performance of non-prestressed elements to the maximum extent possible to save transportation costs by a contractor, i.e., cast the components on-site in the staging area. This contradicts with the option of standardizing non-prestressed pier columns.

The SHRP 2 R04 project considered several aspects to achieve higher cost savings in routine bridges with ABC. One option is to identify 10 or 12 bridges of a similar type requiring replacement and call for bids for that cluster of bridges. Large cost savings will be realized from the fabricators' side, as the forms will be reused for multiple bridges and brings in economy of scale. This is a way of leveraging ABC and precast technology to the maximum. In this case the owner does not need to be concerned about standardization as the contractor can make their own form and can self-perform. Thus, consideration is required in selecting the cluster of similar routine bridges for a contract package to achieve economy of scale. This will have both cost and schedule savings as the prefabrication will be performed similar to an assembly line, and the unit price will go down.

In order to standardize and to identify alternatives, it is vital to have a dialog between the bridge owners, consultants, contractors, fabricators, and the researchers. As an example, Utah DOT, in their process of standardization, conducted several workshops that included contractors, fabricators, and designers to provide their input. At that point, Utah DOT stepped away from the AASHTO PCI girder to the Utah Bulb-Tee girder that became their routine girder.

Q5: Does the design-bid-build method puts more risk on contractors/owners for ABC projects?

A5: The contractors mostly bid on the risk factor; thus, as the risk goes down the cost decreases. When the contractors gain experience, the assumed risk is reduced. Hence, the more ABC projects are performed, more experience is gained, and the cost is reduced. It is a learning curve both on the owner's side and contractor's side. It shall be noted that the DOT shall put the risk where the risk belongs to. The DOT's shall not put all the risk onto the contractor, as some risk does belong to the owner. For ABC projects, the DOTs shall think about assigning appropriate portion of risk to the contractors, rather than putting all the risk onto the contractor.

For the SHRP 2 R04 projects in Iowa and New York, the project team engaged all the local contractors (by working through AGC) from the start of the ABC project and had one-on-one meetings to get their input at 30% of design phase and 60% design phase. Then an information session with all the contractors was conducted prior to the bidding date. This worked very well, and competitive bids were received because the input was received from the local contracting industry itself, rather than one single contractor as in case of CMGC.

Q6: Regarding the connection durability in the closure pour of deck panels, Utah special provisions specify that the contractor shall work with a grout supplier to ensure connection durability. But still within 2 years cracks and leakage were documented at the connections in Utah's ABC bridges. What is Utah DOT's comment on this?

A6: Utah DOT had significant problems with the closure pours and transverse joints between the panels. Utah was using UHPC or HPC for the closure pours and grout for transverse connections. They were unable to identify a *true* non-shrink grout and the decks were cracking and leaking soon in 6 months of project completion. For some of the projects, Utah requested a warranty for the grout connections; however, when the connections started leaking, the contractor blamed the supplier and the supplier blamed the contractor for improper installation. Instead of identifying the perfect grout and trying to warranty the grout, Utah DOT decided to specify longitudinal post-tensioning in all the precast decks. In addition, they placed an overlay on the deck to ensure the connections do not leak.

Ken Price from HNTB has the perspective that the transverse joints crack not because of materials but because of live load demand. The longitudinal joints do not crack in ABC projects but the transverse joints do crack. This is because the decks bend in a longitudinal direction and *arch* in a transverse direction. This justification is based on the performance of the modular decked steel girder system implemented in SHRP 2 R04 project in Iowa. Thus, any transverse joint material subjected to tensile forces due to bending moment will eventually crack. It is recommended that a modest level of prestress or post-tensioning in longitudinal direction will ensure transverse connection durability for numerous years to come.

APPENDIX E

WORKSHOP PARTICIPANTS

Count	Last Name	First Name	Affiliation
1	Abadir	Jane	Somat Engineering Inc.
2	Adefeso	Olukayode	Michigan DOT - Metro Region
3	Alvarez Soto	Lucia	Western Michigan University
4	Awwa	Sam	IBI Group
5	Baker	Nick	Anlaan Corporation
6	Barry	Timothy	Michigan DOT
7	Bedford	Allan	Orchard Hiltz & McCliment (OHM) Inc.
8	Bellgowan	Matt	Michigan DOT - Grand Rapids TSC
9	Boeskook	Shawn	Milbocker & Sons, Inc.
10	Bower	Steve	Michigan DOT
11	Branson	Kirk	Parsons Brinckerhoff Michigan Inc.
12	Broekhuizen	Dan	URS Corporation
13	Bruinsma	Jonathon	Michigan DOT - Grand Region
14	Buchholz	Scott	Tetra Tech
15	Bukoski	Glenn	MITA Building / MCA Main Office
16	Burns	Eric	Michigan DOT - Operations Field Services
17	Chaput	Mark	Michigan DOT- University Region
18	Chaudhry	MT	Federal Highway Administration Michigan Division
19	Chauvin	Mike	HNTB Michigan Inc
20	Chynoweth	Matt	Michigan DOT - Operations Field Services
21	Colling	Timothy	Center for Technology & Training
22	Cooper	Keith	Michigan DOT
23	Coulter	Melzar	Materials Testing Consultants
24	Crace	David	Erickson's Inc.
25	Curtis	Rebecca	Michigan DOT
26	Dashner	Craig	Orchard Hiltz & McCliment (OHM) Inc.
27	Datema	Karl	Michigan DOT - Grand Region
28	Davenport	Ben	Michigan DOT
29	DelaFuente	Jim	Michigan DOT - Grand Region
30	Dombrowski	Christopher	Williams and Works
31	Drakeford	Tim	Wayne County Dept of Public Services
32	Drewek	Matt	AECOM
33	Early	Jason	Fishbeck Thompson Carr & Huber
34	Edwards	Bryan	HNTB Michigan Inc
35	Ellens	Steve	Fishbeck Thompson Carr Huber
36	Elliott	Sharmyn	Somat Engineering Inc.
37	Emerine	Bob	CA Hull
38	Esmacher	Charlie	HNTB Michigan Inc
39	Fox	Tom	Michigan DOT - Grand Rapids TSC
40	Fox	Chad	Erickson's Inc.
41	Garcia	Jose	Michigan DOT
42	Garrett	Greg	URS Corporation
43	Goldsworthy	Joshua	Walter Toebe Construction Company
44	Gronowski	Andy	Wade Trim

Count	Last Name	First Name	Affiliation
45	Grotenhuis	Phil	Michigan DOT
46	Guerrero Ramirez	Camila	Western Michigan University
47	Gunderman	Donald	Michigan DOT - Grand Rapids TSC
48	Hagerman	Marc	Fishbeck Thompson Carr Huber
49	Halbeisen	Al	HH Engineering Ltd
50	Halloran	Mike	Michigan DOT - Southwest Region
51	Hamel	Carrie	Michigan DOT
52	Hansen	Marilyn	Michigan DOT- University Region
53	Harrison	Mark	Michigan DOT
54	Heiss	Mike	Michigan DOT - Grand Rapids TSC
55	Helinski	Mark	Rowe Professional Services
56	Hengesbach	Aaron	Michigan DOT - Aeronautics Department
57	Henry	Chad	Fishbeck Thompson Carr Huber
58	Herl	Patrick	Contech Engineered Solutions, LLC
59	Herman	Brandon	Hardman Construction
60	Hintsala	Brian	AECOM
61	Hoefler	Lacey	HNTB Michigan Inc
62	Homan	Chris	Mannik & Smith Group
63	Ingle	Valerie	RS Engineering LLC
64	Izzo	Paul	DLZ Michigan Inc
65	Jehle	Jerry	Road Commission for Oakland County
66	Jildeh	Raja	Michigan DOT
67	Johnson	Peter	RS Engineering LLC
68	Johnson	Terry	HNTB Michigan Inc
69	Johnson	Chris	Michigan DOT
70	Johr	Roger	Williams and Works
71	Judnic	Victor	HNTB Michigan Inc
72	Juntunen	David	Michigan DOT
73	Kaltenthaler	Albert	TranSystems Corporation of Michigan
74	Katenhus	Steve	Michigan DOT - Bay Region
75	Kathrens	Rich	Michigan DOT - Operations Field Services
76	Kelley	Sean	Mannik & Smith Group
77	Khaldi	Sami	Wayne County Dept of Public Services
78	Kiefer	John	Center for Technology & Training
79	Kind	Erick	Michigan DOT - Grand Rapids TSC
80	Klein	Tia	Hubbell Roth & Clark Inc
81	Koepke	Ken	Michigan DOT - Aeronautics Department
82	Kopper	Kyle	Michigan DOT
83	Kummeth	Michael	DLZ Indiana LLC.
84	Lewis	Mark	Federal Highway Administration Michigan Division
85	Liptak	Richard	Michigan DOT - Cadillac TSC
86	Losch	Greg	Michigan DOT - Aeronautics Department
87	Mahdavi	Ali	Michigan DOT
88	Mayoral	Clint	Michigan DOT

Count	Last Name	First Name	Affiliation
89	McDonald	Jeremy	Fishbeck Thompson Carr Huber
90	McMunn	Creightyn	Michigan DOT
91	McReynolds	Kevin	Michigan DOT - Howard City TSC
92	Mikolajczyk	Matt	Mannik & Smith Group
93	Morley	Brian	Great Lakes Engineering Group LLC
94	Muftah Abduallah	Ramzi	Western Michigan University
95	Needham	Doug	MITA Building / MCA Main Office
96	O'Brock	Jon	Materials Testing Consultants
97	Occhiuto	Chuck	Michigan DOT
98	Olson	Tony	Michigan DOT - North Region Office & Gaylord TSC
99	O'Sullivan	Mike	Alfred Benesch & Company
100	Parmerlee	Doug	URS Corporation
101	Perry	Gregory	Michigan DOT- University Region
102	Phelps	Michael	Z Contractors, Inc.
103	Pratt	Tom	Milbocker & Sons, Inc.
104	Puente	Gonzalo	Michigan DOT
105	Qadeer	Kamran	Fishbeck Thompson Carr & Huber
106	Rajala	Chad	Alfred Benesch & Company
107	Ranger	James	Michigan DOT
108	Reed	Linda	Michigan DOT
109	Reed	Jim	CA Hull
110	Rhoades	Travis	Mannik & Smith Group
111	Robbins	Jenean	Tyme Engineering Inc.
112	Rogers	Corey	Michigan DOT - Operations Field Services
113	Rojas	Pablo	Michigan DOT
114	Schmitzer	Jennifer	Somat Engineering Inc.
115	Schreiber	Fred	Hubbell Roth & Clark Inc
116	Sereseroz	Thomas	RS Engineering LLC
117	Shah	Tanweer	Geotran Consultants
118	Sisson	Jasmine	Parsons Brinckerhoff
119	Solowjow	Leon	Wade Trim
120	Stein	Charles	Michigan DOT - Grand Rapids TSC
121	Stokes	Clayton	Surveying Solutions Inc.
122	Sullivan, PE	Chris	IBI Group
123	Szumigala	Mike	CA Hull
124	Taylor	Louis	Michigan DOT - Mt. Pleasant TSC
125	Tebbe	Susan	Williams and Works
126	Tellier	Thomas	Michigan DOT - Grand Rapids TSC
127	Tenbrock	Mike	Kent County Road Commission
128	Tennes	Chris	Michigan DOT
129	Tiffany	Ken	Michigan DOT
130	Tinkey	Shawn	HNTB Michigan Inc
131	Todorova	Radka	Michigan DOT
132	Toman	Patrick	DLZ Michigan Inc

Count	Last Name	First Name	Affiliation
133	Tornes	Pete	Milbocker & Sons, Inc.
134	Townley	Michael	Michigan DOT
135	Transue	Jennifer	Michigan DOT
136	Turczynski	Bryan	Fishbeck, Thompson, Carr & Huber, Inc
137	Udegbunam	Oge	Tyme Engineering Inc.
138	Valdez	Daniel	Jackson County Department of Transportation
139	Van Portfliet	Randy	Michigan DOT - Superior Region & Escanaba
140	VanDrunen	Nate	Michigan DOT - Grand Region
141	Wagner	Bradley	Michigan DOT
142	Wahed Mohammed	Abdul	Western Michigan University
143	Wanagat	Scott	Macomb County Department of Roads
144	Watkins	Johnny	Tyme Engineering Inc.
145	Weirauch	Catherine	Somat Engineering Inc.
146	Whitlatch	Chase	Alfred Benesch & Company
147	Yip	Danny	Geotran Consultants
148	Zaremski	Jonathan	Somat Engineering Inc.
149	Zokvic	Vladimir	Michigan DOT