Lateral Slide of Multi-Span Bridges: Investigation of Connections and Other Details–Phase I

Final Report
June 2021

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16. Abstract

Lateral slide-in bridge construction, also referred to as slide-in bridge construction (SIBC), has gained increasing attention as a viable accelerated bridge construction (ABC) approach. The use of SIBC is one of several ABC methods being promoted through the Federal Highway Administration (FHWA) Every Day Counts (EDC) program. The Iowa Department of Transportation (DOT) completed its first lateral slide-in bridge project in the fall of 2013 during the replacement of a single-span bridge on IA 92 over a small stream just west of Massena in southwest Iowa.

After that, the Iowa DOT planned to construct a multi-span bridge using slide-in construction techniques, which raised many questions. As such, it was vitally important that Iowa DOT design engineers have the best information regarding the performance of various critical details. The addition of more spans creates a more complex system that requires connections (and other details) that were previously not needed in a single-span slide. Furthermore, the fact that the multi-span bridge would need to slide on abutments plus piers (as opposed to just abutments in a single-span case) created possible uplift and overturning scenarios.

The objective of this project was to develop economical and durable design details to be used with the lateral slide concept with a focus on pier connection details. The ultimate goals with this research and the design/construction of the multi-span bridge were to end up with a bridge that is a strong, durable, economical bridge that can be constructed utilizing the lateral slide method and provide modifications to the Iowa DOT's three-span standards.

The general finding from the field monitoring work was that the current slide-in practice works well with the multi-span steel girder superstructure and the wall pier. No significant response from the substructure was visually observed during the slide-in, and no cracking occurred on the concrete deck or piers. This indicated that the superstructure with steel girders and concrete diaphragms can be built with the lateral slide-in method.

Significant strain was measured from the pile strain gauges. The piles were functionally adequate to carry the vertical load, and the moment carried by each pile was minimal. An uplifting action was captured on Pier 1. However, this effect was minimal on Pier 2.

Based on the results from the work conducted in the four tasks, further research, including laboratory tests and analytical simulation, is proposed as additional Phase II work.

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LATERAL SLIDE OF MULTI-SPAN BRIDGES: INVESTIGATION OF CONNECTIONS AND OTHER DETAILS–PHASE I

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EXECUTIVE SUMMARY

Lateral slide-in bridge construction, also referred to as slide-in bridge construction (SIBC), has gained increasing attention as a viable accelerated bridge construction (ABC) approach. The use of SIBC is one of several ABC methods being promoted through the Federal Highway Administration (FHWA) Every Day Counts (EDC) program. The Iowa Department of Transportation (DOT) completed its first lateral slide-in bridge project in the fall of 2013 during the replacement of a single-span bridge on IA 92 over a small stream just west of Massena in southwest Iowa.

After that, the Iowa DOT planned to construct a multi-span bridge using slide-in construction techniques, which raised many questions. As such, it was vitally important that Iowa DOT design engineers have the best information regarding the performance of various critical details. The addition of more spans creates a more complex system that requires connections (and other details) that were previously not needed in a single-span slide. Furthermore, the fact that the multi-span bridge would need to slide on abutments plus piers (as opposed to just abutments in a single-span case) created possible uplift and overturning scenarios.

The objective of this project was to develop economical and durable design details to be used with the lateral slide concept with a focus on pier connection details. The ultimate goals with this research and the design/construction of the multi-span bridge were to end up with a bridge that is strong, durable, and economical and can be constructed utilizing the lateral slide method and provide modifications to the Iowa DOT’s three-span standards

To achieve the goal, four tasks were completed. In the Task 1 work, relevant information was collected and evaluated by conducting a literature review on various details and construction approaches for previously completed lateral slide projects. In Task 2, a survey was conducted among state DOTs that may have related experience on using the SIBC method on multi-span bridges. The goal of this task was to collect the information on the methods and practices that have never been documented with published details. A significant amount of valuable information was collected from the literature review and survey, and the successful design and construction details were identified and discussed.

In Task 3, the successfully implemented design details were evaluated and summarized based on the findings from the previous tasks. In Task 4, the researchers monitored the construction of a three-span, 300-ft-long, steel girder bridge on IA 1 southwest of Iowa City, Iowa, using gauges during the slide-in.

The general finding from the field monitoring work is that the current slide-in practice works well with the multi-span steel girder superstructure and the wall pier. No significant response from the substructure was visually observed during the slide-in, and no cracking occurred on the concrete deck or piers. This indicated that the superstructure with steel girders and concrete diaphragms can be built with the lateral slide-in method.

Significant strain was measured from the pile strain gauges. The piles were functionally adequate to carry the vertical load, and the moment carried by each pile was minimal. An uplifting action was captured on Pier 1. However, this effect was minimal on Pier 2.

Based on the results from the work conducted in the four tasks, further research, including laboratory tests and analytical simulation, is proposed as additional Phase II work.

CHAPTER 1. INTRODUCTION

1.1 Background and Problem Statement

Lateral slide-in bridge construction, also referred to as slide-in bridge construction (SIBC), has gained increasing attention as a viable accelerated bridge construction (ABC) approach. With lateral slide construction, the majority of the bridge superstructure is constructed off alignment, typically parallel to the final position, and usually on a system of temporary works. The construction of this portion of the bridge is often completed while the original bridge is still open to traffic.

In some instances, portions of the substructure are also constructed while the original bridge is still open to traffic—a technique designed to further reduce traffic impacts. Common techniques for accomplishing this include building substructure elements outside of the original bridge footprint as well as using innovative techniques to complete construction under the bridge with consideration of clearance limitations, stability of the underlying soil, and others.

Once the construction of the superstructure is essentially complete, the original bridge is demolished, and new substructure construction is completed. Then, usually over a relatively short period of time (commonly hours to a day), the new bridge superstructure is slid laterally from the temporary works onto the in-place substructure.

The use of SIBC is one of several ABC methods being promoted through the Federal Highway Administration (FHWA) Every Day Counts (EDC) program. In some states, such as Iowa, the use of ABC has been strategically deployed at locations where traffic volume, access, and other factors drive the need for a very short disruption to the traveling public.

The Iowa Department of Transportation (DOT) completed its first lateral slide project in the fall of 2013 during the replacement of a single-span bridge on IA 92 over a small stream just west of Massena in southwest Iowa. After that, the Iowa DOT planned to construct a multi-span bridge using slide-in construction techniques, which raised many questions.

The addition of more spans creates a more complex system that requires connections (and other details) that were previously not needed in a single-span slide. Furthermore, the fact that the multi-span bridge would need to slide on abutments plus piers (as opposed to just abutments in a single-span case) created possible uplift and overturning scenarios. As such, it was vitally important that Iowa DOT design engineers has the best information regarding the performance of various critical details.

These details needed to be economical and durable while also being practical and constructible. When combined, these attributes will lead to a fiscally responsible ABC solution when multi-span bridges are needed. Although a good amount of general information related to the use of lateral slide as an ABC method was available, very little literature has been published specifically related to such construction for multi-span bridges.

1.2 Objective and Goals

The objective of this project was to develop/identify economical and durable design details to be used with the lateral slide concept with a focus on pier connection details. The goals with this research and the design/construction of the upcoming multi-span bridge were to end up with a bridge that is strong, durable, economical, and constructible and to provide modifications to the Iowa DOT's three-span standards.

1.3 Research Plan

To achieve the objectives, four tasks were completed. In the Task 1 work, relevant information was collected and evaluated by conducting a literature review on various details and construction approaches for previously completed lateral slide-in projects.

In Task 2, a survey was conducted among state DOTs that may have related experience on using the SIBC method on multi-span bridges. The goal of this task was to collect the information on the methods and practices that have never been documented with published details (e.g., lateral slide projects completed by state DOTs that did not have a research component or by contractors that typically protect construction methods as proprietary information).

In Task 3, the successfully implemented design details were evaluated and summarized based on the findings from the previous tasks. Based on the results, additional research needs were identified and recommended for future work.

In Task 4, the bridge construction/replacement over Old Man's Creek on IA 1 was monitored to gain useful insights during the lateral slide-in. The goal of this task was to monitor the lateral slide effects on the bridge and its associated structural elements.

1.4 Report Outline

The results from Tasks 1, 2, 3, and 4 are summarized and presented in Chapter 2, 3, 4, and 5, respectively. This final report covers all of the Phase I work from this project. A plan for additional research work is proposed for Phase II in Chapter 6.

Appendix A provides descriptions of the 10 multi-span bridges that were found to have been constructed using the SIBC approach. Appendix B includes the completed survey questionnaires for these 10 bridges.

CHAPTER 2. LITERATURE REVIEW

The objective of the literature review was to collect and summarize information relevant to SIBC. The focus of this exhaustive literature review was on published information related to lateral slide-in construction. The literature search focused on the implementation of SIBC on multi-span bridges where the lateral sliding force may induce a significant effect on the pier column, foundation, pier diaphragm, etc.

The literature search started from the *Slide-In Bridge Construction Implementation Guide* published by the FHWA (UDOT and Michael Baker Corporation 2013), which provides a comprehensive introduction to the implementation of the SIBC method on bridge structures. Based on the information in this guide and the findings from other literature sources, the general SIBC procedures and characteristics are summarized in Section 2.1. Following that, past bridge construction cases that utilized the SIBC method since the 1990s were found from online resources, research project reports, and technical articles. These resources were reviewed with the results presented in Section 2.2. By reviewing these SIBC projects, the research team gained a comprehensive understanding of the current status of the implementation of SIBC on multi-span bridges.

During this process, the cases that may be related to SIBC of multi-span bridges and the study of pier/foundation behavior during the slide were identified. Another round of literature search and review was conducted to find detailed information or research activities for SIBC cases that may contribute to the final objective in this research project. The results of the second round on the literature review are presented in Section 2.3, Section 2.4, and Section 2.5. The general results from the literature review are summarized in Section 2.6.

2.1 SIBC Procedure

Sliding a constructed bridge is not a new concept and has been successfully implemented in many projects nationwide. The Utah DOT and Michael Baker Corporation (2013) developed the *Slide-In Bridge Construction Implementation Guide* for the FHWA to demonstrate the advantages of SIBC and document how state and local agencies can implement SIBC in typical bridge replacements as a part of their standard business practices.

The authors pointed out that, most often, these projects have been large bridges with high traffic volumes that limited other construction options. The application of SIBC on smaller, routine bridges is relatively new and underutilized. However, state agencies and the FHWA have successfully employed SIBC with small bridge replacements as an innovative option to minimize impacts to the traveling public.

SIBC offers a cost-effective technique to rapidly replace an existing bridge while reducing impacts to mobility and safety. Usually, implementation of SIBC involves the following procedures:

1. Construct a temporary substructure next to the existing bridge as the support for the superstructure of the new bridge.
2. Construct the superstructure on top of the temporary substructure while maintaining traffic on the existing bridge.
3. Construct the substructure under the existing bridge without disturbing traffic.
4. Detour traffic to the new bridge superstructure built on the temporary support and demolish the existing bridge. (The construction of the new substructure sometimes continues during this step.)
5. Slide the new bridge superstructure onto the new substructure. The road closure for the sliding usually takes a few hours to several days.

2.2 SIBC Applications

The researchers identified more than 40 projects in the past 30 years that have used the slide-in method for single- or multi-span bridges from online webpages, research project reports, and technical articles. The researchers reviewed the information on these to gain a full understanding of the current implementation status of SIBC.

Since the objective of the research focus was on multi-span bridges, with an emphasis on the pier region, only those cases that used SIBC on multi-span bridges are summarized in this section. A summary of the details for these 10 multi-span bridges is provided in Table 1.

Table 1. Multi-span bridges constructed using SIBC approach

				Original bridge			New bridge								
No	**Bridge location**	**Year**	**State**	**Total span #**	**Total length (ft)**	**Total width (ft)**	**Total span #**	**Total length (ft)**	**Total width (ft)**	**Max. # of spans (each slide)**	**Beam type**	**Pier type**	**Foundation type**	**Diaphragm type**	**Sliding system**
1	I-405 over Northeast 8th Street Bridge	2003	Washington	6	293	103	2	328	121.5	2	Steel I-girders	Beam column frame	Spread footings	Steel	Roller
2	Hood Canal Bridge	2005	Washington	6	643	30	5	605	40	5	Prestressed bulb tee girders	Beam column frame	Drilled shafts	Concrete	Rollers
3	Elk Creek Bridge	2008	Oregon	6	340	30	3	320.5	38.2	3	Steel I-girders	Beam column frame	Drilled shafts		Bearing pad
4	Ben Sawyer Swing Bridge	2010	South Carolina	>3			>3	1,154	36.5	6	Steel plate girders	Beam column frame (reused)		Steel	
5	I-44 over Gasconade River	2011	Missouri	6	670	34	6	670	36.67	4	Steel plate girders	Beam column frame		Steel	Stainless steel and Teflon sliding surface
6	Sellwood Bridge	2013	Oregon	4	1100					4	Steel Truss				
7	I-84 over Dingle Ridge Road	2013	New York		140	33.3	3	140		3	Double Tee NEXT beams				
8	Larpenteur Avenue Bridge	2014	Minnesota		185.5	61	2	187	75.8	2	Prestressed concrete beams			Concrete	
9	M-50 over I-96	2014	Michigan	4	227	37.5	2	198	71.25	2					
10	Poplar Street Bridge	2018	Missouri	5	2165							Beam column frame (reused)			

Additional information on these 10 projects is summarized in Appendix A. Each description summarizes bridge construction with a focus on geometry information, construction procedures, etc. The type of sliding systems and bridge components near the pier region are also presented if the information was available.

The information in Table 1 indicates that most of the bridges have two to six spans and that the whole bridge was built continuously over the piers and slid simultaneously onto the permanent structure. These construction projects include I-405 over the Northeast 8th Street bridge, the Hood Canal Bridge, and others.

For the bridges with tens of spans and usually constructed over a river, the superstructure was usually divided into units of up to three spans, and each unit was slid into final position using the SIBC approach (sometimes in conjunction with the float-in method). For example, the Ben Sawyer Bridge slid the six approach spans on each end and floated in the steel truss span in the middle.

By comparing the lengths of the new bridges to that of their original bridges, the researchers found that the total length of the new bridges is usually shorter than that of the original bridge, such as the Hood Canal Bridge and the Elk Creek Bridge. This observation shows a good agreement with the findings from UDOT and Michael Baker Corporation (2013), where it was shown that the SIBC method required the construction of the substructure for the new bridge under the original bridge without disturbing the traffic on the old bridge. The common practice to achieve that is to build the new abutment in front of the original one. The new bridge is usually wider than the original bridge due to increased traffic volume.

The information in Table 1 also indicates that the beam-column frame pier is the most frequently used pier type for the construction of the multi-span bridge utilizing the SIBC approach. During the review of the literature, no special consideration seemed to be given to the pier design. And, no issues have been reported for the use of the beam column frame associated with the SIBC method.

With respect to the foundation type, the limited information indicated that both spread footings and drilled shafts were used.

The selection of the material for the diaphragm is mostly based on the type of girder. Both steel and concrete diaphragms were used with the SIBC approach without reports of an issue.

For the selection of the sliding system, it appears when the superstructure in each slide exceeds approximately 300 ft in length or 50 ft in width, the roller support was commonly used, since a large heavier superstructure requires a low coefficient of friction on the sliding track to reduce the lateral sliding force demand.

The researchers found that both steel plate girders and prestressed concrete beams were used for multi-span SIBC.

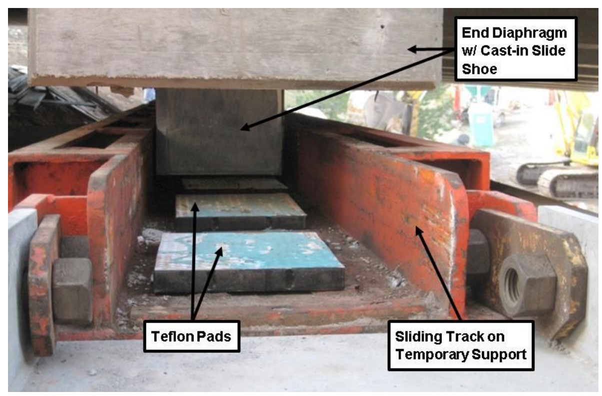
2.3 SIBC Equipment and Techniques

Compared to conventional construction methods, SIBC requires the use of additional equipment to move the new superstructure from the temporary supports to the permanent ones. The special equipment used for SIBC usually includes a sliding system with rollers or bearing pads as the contact between the substructure and the superstructure, an actuating system (sometimes used with a movement control mechanism) to provide the power for the movement, and one or two temporary structures used to support the new or old superstructure. In this section, different types of equipment used during the slide-in procedure are discussed with respect to their effect on the substructure of the multi-span bridge.

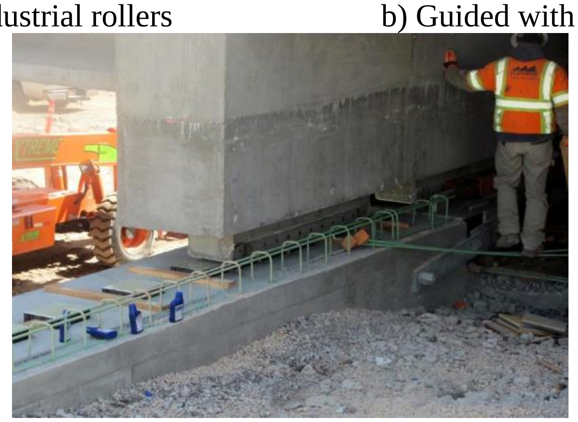
2.3.1 Sliding Systems

Sliding systems provide and maintain a path for the superstructure during the lateral slide. Polytetrafluoroethylene (commonly known as Teflon) pads and rollers (shown in Figure 1) are most commonly used for the slide systems in SIBC.

a) Guided with industrial rollers



b) Guided with Teflon pads



c) Unguided with Teflon pads

UDOT and Michael Baker Corporation 2013, FHWA

Figure 1. Sliding systems

Industrial rollers are usually installed under the girders or end diaphragm of the new bridge and used with a sliding track. The sliding track maintains the movement in the slide direction. One of the advantages of using rollers is that, compared to the Teflon pad, sliding friction is very low in roller systems. The coefficient of friction of the roller system is usually less than 5% and the breakaway friction is close to the kinetic friction since the sliding velocity is very low. The low friction of coefficient means less external force is needed to initiate and keep the movement of the superstructure and, as a result, the reaction force on the temporary and permanent substructure is low.

UDOT and Michael Baker Corporation (2013) list a few major drawbacks on roller systems, including that the large point load occurs under each roller, binding or jamming of rollers may occur if not aligned properly, and start and stop ability should be provided during the slide since the dynamic coefficient of friction is low. The large point load requires more attention on the design of permanent and temporary substructures. In addition, vertical jacking is required to remove the rollers after the superstructure is moved to its final position.

Teflon pads are the most commonly used sliding system in SIBC approaches. This method uses elastomeric or cotton duck bearing pads topped with Teflon to slide the bridge into place. The pads are usually lined along the temporary supports and permanent substructures, and the bottom of the bridge diaphragm becomes the sliding surface. Slide shoes or sliding blocks can be cast into the diaphragm and wrapped with a sliding surface such as stainless steel. With this method, the final sliding pads on which the bridge stops can be left in place to act as the final bearings.

Aktan and Attanayake (2015) indicated that the coefficient of friction associated with Teflon pads could be as much as 20%. The Bridge Engineering Center (BEC) research team at Iowa State University tested the behavior of the bearing pads to determine if excessive shear deformation occurs such that the bearing pads may “roll” during construction. The results indicated that the coefficient of friction was calculated to be approximately 0.11 for the non-lubricated tests and 0.07 for the lubricated tests. For the multi-span bridge, a greater friction coefficient may result in a larger reaction force to the pier column and the foundation structures.

There is no best system for any specific application (UDOT and Michael Baker Corportation 2013). Geometry, weight, tolerances, and experience are the parameters considered in the selection of slide systems. Sliding resistance of Teflon pads is relatively greater compared to rollers, resulting in a greater reaction force on the substructure. Parameters that affect Teflon-steel interface friction include sliding velocity, normal pressure, Teflon composition, steel sliding surface roughness, surface treatment (lubricant applied at the interface), temperature, and the angle between the surface polishing of steel and the slide direction (Hwang et al. 1990).

Ridvanoglu (2016) divided the sliding system into two categories: **guided and unguided systems**. Guided systems include restraints in the transverse direction to limit movement in the direction perpendicular to the slide. Unguided systems provide no transverse restraints. Both Teflon pads and rollers can be utilized in conjunction with guides (tracks) to provide smooth sliding with restraints to transverse movement, but the use of Teflon pads alone cannot provide any transverse restraints and belong to the unguided system.

On multi-span bridges, guided systems over the pier could prevent drifting of the superstructure, but may result in binding due to a development of large transverse forces. This can possibly damage the pier since it is generally not designed for these particular lateral slide forces. On the other hand, unguided systems could prevent force development in the transverse direction, while excessive drifts may result in loss of alignment.

These undesirable situations in guided and unguided systems are generally inevitable because of the uncertainty of sliding resistance. Ridvanoglu (2016) pointed out that transverse forces should be considered in the design of the temporary and/or permanent substructure in the uses of guided systems.

2.3.2 Actuating Devices

Actuating systems are used to provide force to initiate and maintain the slide. Sliding can be completed by pushing, pulling, or the combination of both. Most commonly used actuating systems include hydraulic rams, mechanical pulling devices, and prestressing jacks. To provide enough force for the slide, multiple actuating devices placed at different locations are usually required.

Ridvanoglu (2016) indicated that the difference between the applied force and resistance is not constant throughout the slide-in. This may result in binding on one side, with uncontrollable drifting of the superstructure.

Hydraulic jacks are usually installed along with Teflon pads and a sliding track system to provide an anchor to push against and guide the bridge to its final alignment (see Figure 2-a).

a) Hydraulic jacks b) Mechanical pulling devices c) Post-tensioned jacks
UDOT and Michael Baker Corporation 2013, FHWA

Figure 2. Actuating devices

To execute the slide, the jacks extend to full stroke to push the bridge forward while anchoring against the slide tracks or temporary supports. On a multi-span bridge, the hydraulic cylinders are usually connected to superstructure diaphragms over the abutments and piers, and cylinders are capable of pulling and pushing.

Ridvanoglu (2016) indicated that capacity and stroke length of the hydraulic cylinders are important for the slide, especially to prevent binding. Binding may result in damage to the superstructure in the use of longer stroke-length cylinders if the binding occurs in the beginning of the push cycle.

Mechanical pulling devices, such as a winch or crane, can pull the superstructure along rollers or Teflon pads to its final position (see Figure 2-b). Separate pulling devices can be used at each pulling location, or a system of pulleys can be used to allow one mechanical pulling device to pull simultaneously on multiple points. If using one pulling device with a pulley system, the bridge is uniformly moved on all pull points.

One of the major drawbacks of mechanical pulling devices pointed out by UDOT and Michael Baker Corporation (2013) is that there is no ability to “back up” the pull without a separate pull system set up on the opposite side of the structure. Consequently, the system is usually used along with hydraulic jacks.

Post-tensioned jacks are small jacks used to pull an anchored post-tensioned strand or threaded high-strength bar and push the bridge into place on rollers or Teflon pads (see Figure 2-c). UDOT and Michael Baker Corporation (2013) pointed out that it requires abutment or diaphragm designs that allow anchoring of the post-tensioned strands and transfer from a pulling force on the strand to a pushing force on the superstructure, and there is no ability to “back up” the pull without a separate pull system set up on the opposite side of the structure.

Ridvanoglu (2016) indicated that these systems are generally used with a pulling operation since jacks can only apply tensile forces. In addition, cable systems do not require settling for each pulling cycle. UDOT and Michael Baker Corportation (2013) indicated that the cable flexibility and prestressing losses could generate jerks in movement.

2.3.3 Movement Control Mechanisms

Two approaches are used to control movement during the slide: pressure-regulated systems and servo-controlled systems. Pressure-regulated systems are used more commonly than servo-controlled ones.

Pressure-regulated systems are capable of controlling only the hydraulic pressure applied to a jack. Combined pulling and pushing methods are utilized multiple times. Pressure-regulated systems should only be used with guided slide systems, along with attentive visual monitoring of movement and a contingency plan.

While most cases require force applications that result in equal displacements of supports, it is possible to slide the structure to a skewed position along a curved path of travel. The Sellwood Bridge move in Oregon required a final position at a skew, with a total translation of 66 feet and 33 feet for the west and east ends of the structure, respectively. The truss structure moved along a curved path due to the skewed alignment and thus, the steel translation beams were designed to account for the curve. The move was accomplished using a “digitally-controlled power pack” that regulated the amount of fluid going to each jack. Jacks at the west end were regulated to push twice as fast as the jacks on the east end, with jacks between end supports pushing at proportional rates.

Ridvanoglu (2016) indicated that pressure-regulated actuating faces a differential friction result with drifting of the superstructure. This event may be prevented by monitoring and/or using a short stroke-length cylinder.

Servo-controlled systems monitor displacements and calibrate applied pressure automatically to balance the movement. A servo controller can be utilized to monitor real-time displacement in different rails in order to control an equal sliding rate. Drifting delays the slide and increases the duration of the slide-in (Ridvanoglu 2016).

Pressure in each abutment or bent is synchronized and automatically corrected to ensure equal displacements. Servo-controlled systems maintain an aligned slide-in given the difference in friction resistance is balanced with controlling the applied pressure. Servo-controlled systems should be utilized with unguided slide systems to eliminate the effects of differential friction resistance.

Aktan and Attanayake (2015) indicated that the control of forces using the pressure control valves at the manifold is often quite slow. To allow accurate and rapid force control during the move operation, a servo controller is required. The inclusion of the servo controller requires the use of electronics and most likely a field computer.

On a multi-span bridge where more than two actuating devices are used for each slide, multiple controllers can be synchronized to achieve equal force or displacement and reduce the possibility that binding occurs; as a result, it reduce the chance of damage to the superstructure, substructure, and actuating devices.

2.3.4 Locations of Force Application

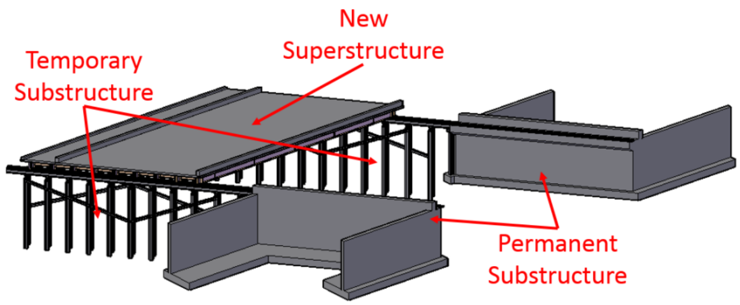
Most of the bridges constructed in the US utilizing the SIBC approach have been single-span bridges. However, the SIBC approach has been successfully used to move up to six-span superstructures. The superstructure of bridges with more than six spans are usually divided and pre-fabricated as six-span units and slid in individually. For single-span bridges, it is a common practice to place an actuating device at each abutment. For bridges with more than one span, the actuating devices have usually been placed at both the abutment and the pier diaphragms. However, coordination of separate mechanical systems is required at each push/pull location to perform a smooth slide-in.

2.3.5 Temporary Structures

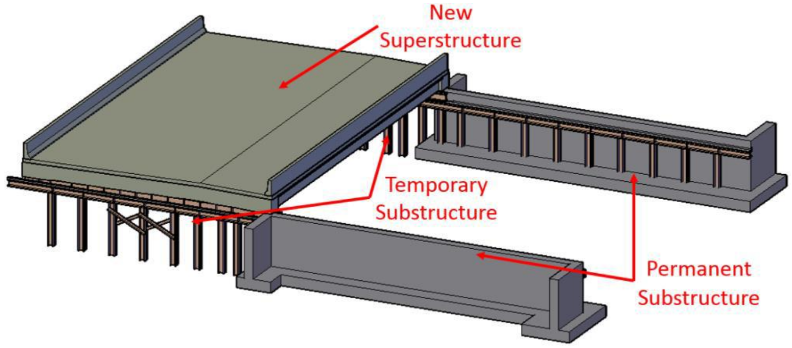
To slide a multi-span superstructure using the SIBC method, temporary support structures are required at the pier location before and during the lateral slide. Temporary structures include a foundation, a frame system, and a sliding track. Loads transferred to temporary supports by friction forces need to be considered as well as gravity loads, such as weight, traffic, and equipment, in the design.

Another consideration to take into account with temporary structures is their use is not only limited to the bent for the new superstructure but can serve as a bent for the old superstructure. In the Oregon DOT's Elk Crossing bridge project in 2008, a temporary bent was used on either side of the existing structure to construct the new superstructure, and to quickly remove the existing superstructure. The existing bridge was freed and jacked laterally onto temporary supports, with the new superstructure being jacked laterally into alignment afterward. This method saved the need for full demolition to clear the alignment for the new superstructure and reduced closure time for the single structure to one weekend.

UDOT and Michael Baker Corporation (2013) indicated that defining the load path for the sliding forces is an important step when designing temporary supports. Force development in the transverse direction of the slide is generally disregarded in the design, yet field observations and slide monitoring studies show that forces develop in the transverse direction. Ridvanoglu (2016) classified temporary structures into two categories: inline and in-front temporary structures. **Inline temporary structures** resist superstructure loads during construction and the initial stage of the slide (see Figure 3-a).



a) Inline temporary structure



b) In-front temporary structure
Ridvanoglu 2016, Western Michigan University

Figure 3. Temporary structures

An inline support is connected to the permanent structure, and sliding is maintained from temporary supports to the permanent substructure. Design and construction of the connection between the temporary and permanent substructure has significant importance to assure a smooth transition during the slide. Axial forces, shear forces, and moments can be transferred through the connection when the temporary support is continuous. Bolts are the most common devices to provide continuity of the connection. Continuous connections are most favorable since they provide a smoother path for sliding and minimize temporary support-related binding problems.

Cold joints, hinges, and solid grout are used and classified as semi-continuous connections. Semi-continuous connections limit load transfer in some directions. A discontinuous connection is not recommended since it may result in differential deflections at the connection, which prevents a smooth transition resulting in an increase in slide resistance. Development of a large point load is possible just before crossing from temporary supports to a permanent substructure, which can result in a deflection difference creating slide obstacles.

An important lesson learned from the I-44 over the Gasconade River Bridge was to cast or erect the temporary bent such that it has a constant elevation across the top. This facilitates an easier process with sliding the structure, but typically requires a minor modification to the original bridge design. Typically, the bridge crown is achieved through a stepped cap on the pier, but this would obviously hinder any slide efforts. Therefore, to achieve a flat sliding surface, the crown can be created by thickening each bearing plate the same amount as any removed step. This allows the bottom of bearings to be at a constant elevation and facilitate a slide regardless of deck crown.

However, if constant temporary or permanent bent elevations are not possible, SIBC can still be completed even on a slightly sloped structure, as seen in the 2003 I-405 NE 8th Street Bridge slide. The structure was slid in 2 halves split down the length of the structure and formed a crown in the roadway cross-section of 2 percent, where the slopes of the temporary or permanent cap beams were sloped to match. Even with each half coming in at 4,400 kips, through the use of an innovative slide system at the time, the structure was successfully rolled up the 2 percent grade.

In-front temporary structures include construction of a temporary support system for the full slide-in operation (Figure 3-b). A lateral slide is operated on a temporary structure, and transfer to the permanent substructure is performed after the slide for the permanent alignment. This system requires vertical lifting after the slide to place the superstructure in its permanent location. In addition to general considerations, eccentric loads can develop on the permanent substructure when an in-front temporary support system is utilized. Using the foundation of the permanent abutment to support the temporary support system and the connecting rail girder to the abutment cap in the permanent location has been documented for past projects. However, no record indicated that this type of temporary system has been used at a pier location.

Foundation selection for the temporary support generally depends on the soil conditions. Driven piles, drilled shafts, micro-piles, or spread footings can be used. The foundation of the permanent piers can also be used as a foundation for temporary supports in specific applications.

Ridvanoglu (2016) pointed out that the settlement and deflection of the system subject to the full bridge load should be calculated in order to determine the elevation to initially set the temporary support. It is also recommended that a moving load analysis be performed for the temporary support system considering forces developed in the direction of gravity, the slide-in, and the transverse of the slide-in. Furthermore, if traffic is shifted to the new superstructure while on the temporary structures, a traffic live load analysis should be performed.

2.4 Design Considerations for Permanent Substructures

The design considerations discussed in this section focus on the permanent substructure, foundation solution, and diaphragm type. The foundation solution was studied for a permanent pier. The foundation solution for the temporary structure was covered just previous to this at the end of Section 2.3.5.

2.4.1 Special Considerations

The slide-in process in the SIBC approach has special requirements on the design and construction of the substructure near the pier. The most commonly experienced challenges for the selection and construction of substructures include the large horizontal loading induced by the slide-in process, influence of the new foundation on the existing substructure, and limited headroom.

The first challenge to overcome is the **large horizontal loading** during the slide-in process. The magnitude of the force required to initiate and maintain the movement of the superstructure depends on the weight of the superstructure and the coefficient of friction between the superstructure and the substructure.

Aktan and Attanayake (2015) indicated that the weight of the superstructure to be moved is generally in excess of one million pounds, so the force required to initiate the motion will be about a half million pounds. Usually, the design of bridge foundations do not consider the large horizontal forces induced by ABC implementations such as SIBC due to pull or push mechanisms. Hence, it is essential to evaluate the capacity of the substructure and foundation before the slide-in.

If the foundation lacks the required lateral load capacity, temporary bracings can be designed to support the substructure and foundation. For the pier structure, the challenge can be overcome by using the in-front temporary structure or through reinforced design of the substructure.

The second challenge to overcome is the **influence of the new foundation on the existing foundation** since, most of the time, the SIBC approach requires construction of the new foundation next to the original foundation, and the fill must be excavated and retained against the existing foundation.

Aktan and Attanayake (2015) indicated parameters such as the amount of displaced soil within the vicinity of the constructed foundation and the equipment used have a significant impact when the foundation is built in proximity to a structure. The dynamic effect of installing a new foundation adjacent to an in-service bridge is also a consideration in SIBC projects. To overcome this challenge, spread footing foundations, drilled shafts, auger piles, and micro-piles with proper installation methods are recommended.

The effect of vibrations on the old foundation due to pile installation should also be considered. Zekkos et al. (2013) developed a tool to estimate ground vibration due to pile driving. This tool has been verified for a limited number of soil types. Even with limitations, such tools need to be utilized to predetermine the potential dynamic effects for planning purposes.

Finally, during foundation installation, the existing bridge response needs to be monitored to assure its stability.

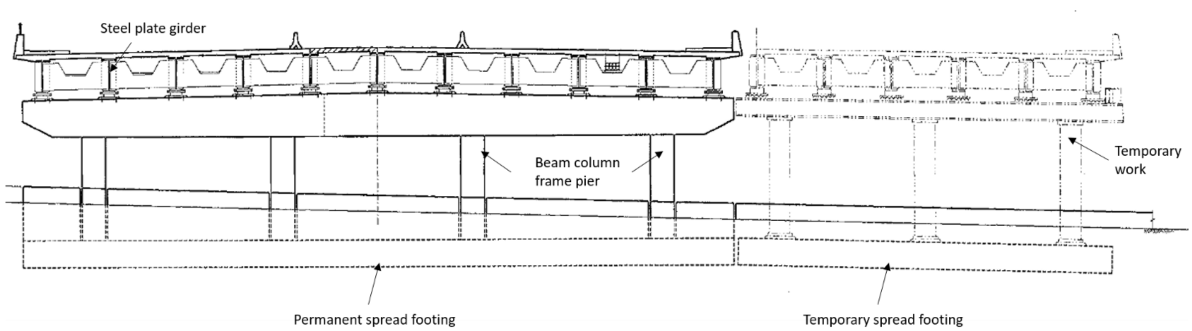
Usually, the SIBC approach requires the construction of the substructure underneath the existing structure when traffic remains open on the existing structure. The **headroom limits** the construction of the foundation and use of various equipment. This challenge can be overcome by both design and the construction method. UDOT and Michael Baker Corporation (2013) indicate that it is a common practice to design the new bridge with a shorter span length than the existing bridge, which enables the new abutments to be constructed underneath the existing bridge prior to its demolition.

For the pier, a straddle bent can be used to install foundations outside the existing bridge footprint. The bent is designed to span between the two foundations. When using a straddle system, deflection of the spanning element (seat) during the slide and in the final configuration should be considered. In addition to using typical columns and bent caps, hammerhead piers and piers with two outriggers, precast posttensioned segmental piers, and prestressed or posttensioned bent caps are also options for SIBC projects.

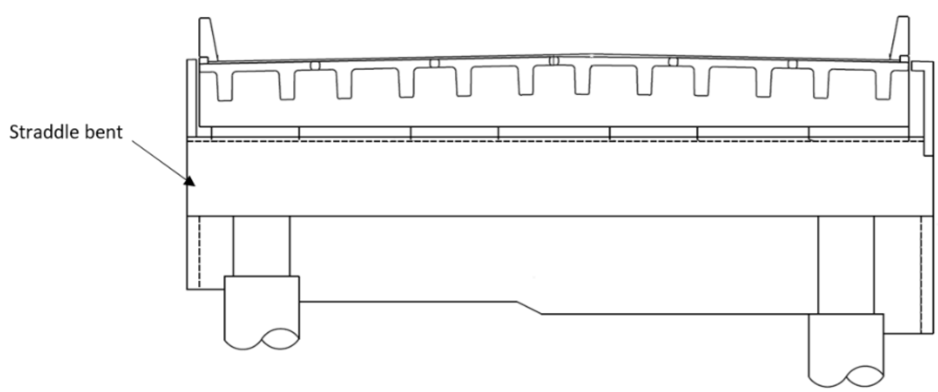
2.4.2 Foundation Solutions

Phares et al. (2019) studied the available foundation types for construction under existing bridges. The use of shallow foundations, drilled shafts, and micro-piles were recommended. Furthermore, supported excavation is recommended to assure the structural stability of the in-service bridge.

Spread footings are the simplest and most cost effective foundation alternative when soil conditions permit. Spread footings do not require excessive headroom during construction, and performance is the same as that with a traditional construction project. Figure 4-a shows the plan for the beam-column frame pier built on spread footings for the I-405 Bridge over NE 8th Street in Washington.



a) Beam-column frame pier on spread footing (I-405 over NE 8th Street, Washington)



b) Drilled shaft (I-84 bridge, New York)

Figure 4. Substructure type

Drilled shafts are another alternative for the new bridge foundation, as shown in Figure 4-b for the I-84 bridge in New York. Note that the construction quality of drilled shafts with unsupported excavations could be a concern. Supported excavation for drilled shafts can assure the stability of the in-service bridge as well as foundation construction quality. Crosshole sonic logging can identify concrete consolidation problems with drilled shafts. Technologies such as compaction grouting and jet grouting have been successfully used to remedy drilled shaft construction flaws.

Micro-piles can be used when deep foundations are required and traditional piles cannot be driven under the existing bridge due to limited vertical clearance. A micro-pile is a small diameter pile (typically less than 12 inches) that is drilled and grouted. Micro-piles can be used in areas with low headroom due to their smaller size and segmental installation, which allow the use of smaller equipment. A new bent with micro-piles constructed near an existing foundation must avoid conflicts with any existing battered piles. Since micro-pile cross-sectional areas are smaller compared to other deep foundation systems, the buckling and lateral load capacities could be a concern.

An additional solution for deep foundations is to core through the existing deck and drive the piles through holes in the deck. This method allows for typical pile arrangements and minimizes quantities. The primary concerns are traffic control with additional impacts to traffic, covering or patching of the core holes, and the potential to damage existing girders. A review of past construction documentation indicated that micro-piles have not yet been utilized underneath the pier on a multi-span bridge constructed utilizing the SIBC approach.

Sometimes, the existing foundation can be reused for the new structure. However, only one project report was found where the existing foundation was reused. This is because the new bridge footprints are usually different from that for existing bridges. If the new bridge is on the same or partially on the same footprint, foundation reuse potential or replacement can be evaluated. The foundation reuse decision heavily depends on the availability of good quality design and construction records as well as the current condition of the foundation. Assessment of an unknown foundation requires a detailed investigation to collect the necessary data.

The Illinois DOT (IDOT 2011) developed a comprehensive procedure and guidelines for foundation reuse. According to that, the existing substructure and foundation elements are assumed to have adequate load capacity for reuse without a detailed structural analysis when the following conditions are satisfied:

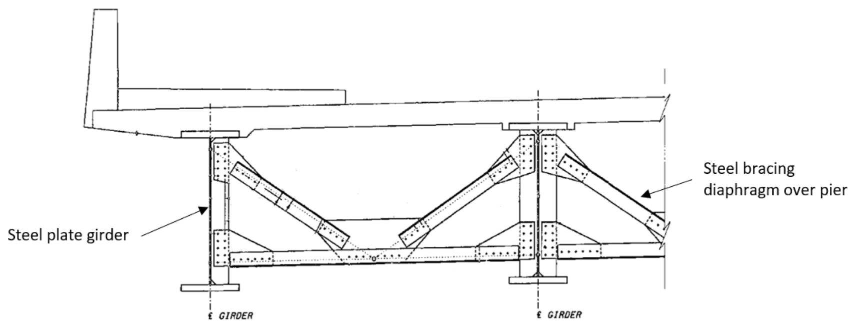
- The substructure elements are in good condition (National Bridge Inventory [NBI] condition rating of 6 or higher) and show no significant structural distress under existing live loads
- The proposed service dead load is not greater than 115% of the original design service dead load
- There is no significant reconfiguration of loads (i.e., no changes to bearing locations or substructure fixities)

2.4.3 Diaphragm Types

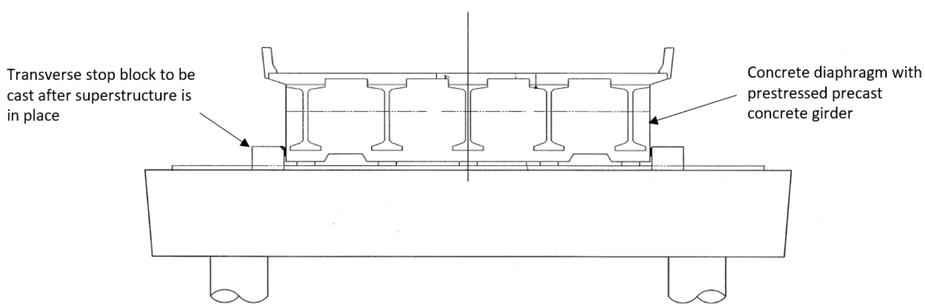
A detailed literature search on the use of different diaphragm types over the pier for SIBC projects was conducted; however, little relevant information was found. More information related to the end diaphragm was found, which might give some hints on the design of the diaphragm over the pier.

For example, UDOT and Michael Baker Corporation (2013) indicated that the solid end diaphragm on semi-integral abutments provides a large, rigid member to jack up the bridge and mount the various sliding systems. The continuous diaphragm allows rollers or sliding shoes anywhere along the abutment (not just underneath the girders). Avoiding bearing points in the center of the abutment beam can minimize permanent moment loads and deflections. In addition, excessive deflections of the seat can cause sliding supports on the end diaphragm to lose contact with the abutment seat and require the end diaphragm to span between two adjacent sliding supports that still have contact. One solution to this is to design the end diaphragm to span over one slide support that loses contact. Another solution is to design the end diaphragm stiffness to allow flexibility and redistribution of the load as the seat deflects.

A review of bridge plans indicated that both steel bracing diaphragms and concrete diaphragms have been successfully used for steel plate girder bridges. The I-405 bridge over NE 8th Street in Washington utilized steel bracing diaphragms over the pier, as shown in Figure 5-a, while the Hood Canal Bridge, also in Washington, used concrete diaphragms, as shown in Figure 5-b.



a) Steel diaphragm (I-405 over NE 8th Street, Washington)



b) Concrete diaphragm (Hood Canal Bridge, Washington)

Figure 5. Diaphragm type

On the I-44 over the Gasconade Bridge slide, steel W shape diaphragms were used for the end and pier diaphragms. Originally designed for conventional construction, these items required design modifications to meet the needs of the SIBC system. The diaphragms had to transfer the pushing loads into the superstructure more effectively and were redesigned accordingly. Bearing stiffeners and connection plates outside the diaphragm provided the connection to the jacks for lateral movement. Additionally, due to clearance limitations, the diaphragms were designed to handle the vertical jacking loads necessary for transition of the bearings. These two design modifications showcase the need for special considerations regarding the bridge diaphragms when using SIBC.

While some modifications are necessary, it was noted that these were the only design modifications required for the structural steel due to the SIBC method. Lastly, it was also noted that the flexibility of the steel superstructure was prevalent in ensuring no damages or cracking occurred from moving the structure into place.

Another design detail to consider from New York DOT's I-84 Bridge over Dingle Ridge Road is the use of diaphragms as the sliding surface rather than the beam bearings. This bridge was comprised of precast NEXT beams, that sat on a prefabricated rigid diaphragm outfitted with 4 slide shoes. The design was done this way to meet the slide elevation low and avoid conflict with other structures onsite.

2.5 Research Investigations for SIBC

Although SIBC has been used for decades, few research activities have been conducted to study the structural performance during the slide-in. The research team found that two approaches have been used to investigate the performance of structures during the lateral slide: field monitoring and finite element simulation.

2.5.1 Field Monitoring During SIBC

Most of the SIBC projects were monitored with **conventional monitoring** tools to ensure successful completion of the project. UDOT and Michael Baker Corporation (2013) recommended use of a conventional monitoring plan in each SIBC project to control horizontal and vertical alignment of the bridge superstructure during the bridge slide-in. They suggested monitoring superstructure rotation around the longitudinal and transverse axes by measuring elevation or by using other methods approved by the project engineer. The authors also suggested observation and reporting of excessive deflections, twist, and change in longitudinal and transverse gradients.

Ridvanoglu et al. (2017) suggested including a monitoring plan regardless of the selected structural system for construction. The report suggests using an actuating system under displacement control that utilizes synchronized self-monitoring systems to control superstructure movement and maintain the move at a steady rate. Typically, a conventional monitoring plan includes monitoring the hydraulic manifold pressure and displacements in the direction of the slide and transverse to the slide.

Shutt (2013a, b, and c) indicated that in order to prevent drift, displacement in both actuating systems should be monitored during the slide. Uneven movements are frequent, and monitoring the displacement is essential for early corrections, which may prevent misalignments. Displacements are usually monitored using measuring tapes, total stations, or servo-controlled monitoring systems. Hydraulic manifold pressure is measured using pressure gauges, load cells attached to actuators, or computerized servo-controlled monitoring systems.

In addition to conventional monitoring of the slide-in process, SIBC projects have been conducted **monitoring for specific interests**. Akant and Attanayake (2015) performed field monitoring to investigate abutment movement when the old superstructure was demolished. An automated robot with six targets was installed on each abutment wall and used for monitoring. The robot was programmed to measure the displacements of the abutment walls continuously and report any readings that exceeded the tolerances.

The Michigan US 131 over 3-Mile Road bridge slide-in monitored railing girder and deck displacements using nine targets on the deck and seven targets on each railing girder. During the pulling operation, the pressure was kept equal on both jacks and adjusted manually as needed.

Pier displacements were monitored during the slide of a four-span bridge on M-50 over I-96, in Michigan. During the bridge slide, the pier was instrumented with targets, and the movement was measured with non-contact laser equipment. The targets were mounted on the bent cap and the columns. The laser tracker was located with a view of all targets, but about 150 ft away from the targets. The displacement data measured during monitoring were used to calculate forces applied to the pier during the slide in all three directions.

Ridvanoglu et al. (2017) monitored the slide-in process of the M-100 bridge over the Canadian National (CN) Railway in Michigan to capture the superstructure rocking during the slide-in. Two accelerometers (one in the direction of the slide and the other in the direction perpendicular to the slide) were mounted on the bridge deck. The bridge slide was performed with a series of discrete push cycles. Data acquisition during each cycle was synchronized by visually observing and recording the start and end of each event. Acceleration response of the superstructure was recorded throughout each slide event. Substructure and actuating system design forces were estimated from the assumed friction coefficient of the sliding surfaces.

The researchers concluded that acceleration monitoring is sufficient in quantifying transverse forces and the differential friction developed between tracks during the slide of a simple-span superstructure. Measuring acceleration in multiple directions at a single location is also sufficient for calculating friction differences between sliding tracks for a single span. The results indicated that the large difference in the friction coefficient between tracks created rocking of the superstructure and generated transverse force applied to the temporary structure. The differential friction coefficient of 1.09% between the two tracks generated a transverse force of 0.63% of the superstructure weight.

2.5.2 Finite Element Simulation for SIBC

Ridvanoglu (2016) developed finite element models using ABAQUS/Explicit to study the influence of different sliding and actuating system on structural behavior. Two completed SIBC projects in Michigan were used as the prototype for simulation development.

The first model described the lateral bridge slide of the US 131 Bridge over 3-Mile Road. This model's simulations included unguided and guided sliding systems with Teflon pads, pressure-regulated and servo-controlled actuation systems with a pulling method, and an in-front temporary sliding support structure.

The second model described the lateral bridge slide of the M-100 Bridge over the CN Railway. Simulations on this model included a guided sliding system with rollers, a pressure-regulated actuating system with a pushing method, and an inline type of temporary sliding support structure.

Simulation results were analyzed to identify sources of the observed challenges and to verify and quantify completed SIBC project outcomes. Ridvanoglu (2016) found that simulation results are useful in identifying the time histories of forces possibly developed on the sliding surface and at the base of temporary structures. Displacements of temporary structures were also calculated through simulations.

2.6 Literature Review Summary

A comprehensive literature search was conducted to find relevant information on the implementation of SIBC on multi-span bridges. However, limited public information was found that directly related to the substructure behavior subject to the lateral slide load. One of the reasons is that not many research activities have been conducted to investigate the substructure response during the slide. Another reason is that some methods and practices have never been documented with published details.

CHAPTER 3. STATE DOT SIBC SURVEY

Despite the fact that a significant amount of information was extracted from technical reports and papers published in hard copy and/or electronic format, the researchers found that some methods and practices have never been documented with published details, including lateral slide projects completed by state DOTs that did not have a research component and by contractors that typically protect construction methods as proprietary information. To obtain additional relevant information, after coordination with the project's technical advisory committee (TAC), the research team reached out to state DOTs and private industry to collect first-hand information about the state of the practice.

3.1 Survey Development

The focus of this portion of the information collection was on lateral slide projects and the details that were used therein. As stated in the project objective, the primary focus of this project is on connection details at/on/over the piers. The following is a list of major details that were of interest during information collection and synthesis:

- Design and detailing for pier overturning
- Performance of steel and concrete diaphragms over piers
- Kinetic friction levels as the bridge transitions from temporary supports to the final substructure
- Deformations of temporary supports during slide-in operations
- Dynamic impact factors associated with multi-span slides
- Efficiency, drawbacks, and advantages of two- and four-point pushing/pulling
- Efficiency, drawbacks, and advantages of pushing and pulling
- Steering control during the slide to prevent binding, especially with four support points
- Tracking of lateral slide progress to minimize lateral flexural stresses at continuous girders at piers

In addition, extra attention was given to the identification of any information that may be useful to the Iowa DOT lateral slide project. To collect comprehensive answers to questions, a questionnaire was developed to include all of the major and additional questions. The questionnaire had five sections: 1. Basic information, 2. Sliding system, 3. Substructure near pier, 4. Superstructure near pier, and 5. Investigation. Each section included detail questions as shown in Table 2.

Table 2. Sample questionnaire

1. Basic information			
1.1 Bridge ID		1.2 State	
1.3 Project year		1.4 Total number of spans	
1.5 Span length (ft)		1.6 Total length (ft)	
1.7 Total width (ft)			
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it?			
2.4 Sliding system (Over pier):			
2.5 What was the friction level?			
2.6 Type of steering control system: Displacement control/Pressure control/Other__________			
2.7 What was dynamic impact factors associated with multi-span sliding?			
3. Substructure near pier			
3.1 Foundation type		3.2 Pier type	
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance?			
3.4 What method was used to overcome the uplift force during sliding? How was the performance?			
3.5 Temporary structure type:			
3.6 Was there significant deformations observed on the temporary works during sliding operations?			
4. Superstructure over pier			
4.1 Girder type		4.2 Diaphragm type	
4.3 How was the performance of the diaphragm over piers?			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result?			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process.			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process.			

Given there were many detailed questions in the questionnaire and filling out a lengthy questionnaire can be boring, the research team decided to take the following approach:

1. Email the target state DOT to request for SIBC project documentation: plans, design drawings, etc.
2. Fill out the questionnaires based on the documentation provided by DOT.
3. Contact for phone interviews to ask questions that cannot be answered by the documentation to fill in more on the questionnaires.

The experience of the research team indicates that much more can be learned through follow-up personal communications/phone call interviews, so this was planned as a second step for information collection.

The survey requests were sent to 11 state DOTs that may have already built a multi-span bridge using the lateral slide-in approach, as shown in Table 3.

Table 3. State DOT survey response summary

	States	# of multi-span SIBC	Interview
1	Missouri	2	Completed
2	Washington	2	Completed
3	Minnesota	2	Completed
4	Oregon	2	Completed
5	Michigan	1	Completed
6	New York	1	Completed
7	South Carolina	1	Completed
8	California	0	None
9	Colorado	0	None
10	Florida	0	None
11	Utah	0	None

These 11 state DOTs were selected because the literature review results indicated they had at least used the SIBC method to build a single-span bridge.

The first contact email message asked only for the existence of a multi-span bridge built using SIBC and for related documentation including bridge drawings, report, journal articles, etc. Four of the 11 DOTs reported to have two multi-span bridges that used SIBC, three reported to have one multi-span bridge that used SIBC, and the other four DOTs didn’t have any.

After this first round, the research team filled in the questionnaire (shown previously in Table 2) utilizing the documentation provided by the state DOTs. The results indicated questions that could be answered using the documentation provided by the DOTS were very limited. Hence, the second round interviews were performed to directly collect the information through personal communications.

3.2 Survey Results

The questionnaire responses compiled through the first and second rounds are included for each bridge in Appendix B. Ten multi-span bridges had been constructed utilizing the SIBC approach in the 11 states that were surveyed. Table 4 summarizes the basic information for these 10 bridges.

The results indicate that the maximum number of spans in each slide that has been performed is six. The length of the bridge superstructure could be as long as 2,165 ft (Poplar Street Bridge), although it was only slid a few feet for the bridge widening. With respect to the bridge components, both steel and concrete beams and diaphragms have been used with SIBC. The most frequently used substructure type was the beam-column frame pier with a spread footing foundation, although drilled shafts and driven piles were also used. In general, the lateral force was applied at all of the diaphragms over the abutment and pier. However, the M-50 over I-96 Bridge did successfully move a two-span bridge with lateral force applied only on the diaphragms over the abutments. Both Teflon pad and roller systems have been used on multi-span bridges, and there were no complaints on the performance of the sliding system. Both steel and concrete temporary structures had been used with inline setup. No outline setup had been used for a multi-span bridge.

The New York State DOT (NYSDOT) indicated that the friction level assumed during the design of the I-80 Bridge was about 7% to 10%. For pier overturning, most of the DOTs did not check it before the slide-in, with the exception of the Missouri DOT (MoDOT), which did check it for the I-44 Bridge over the Gasconade River. All of the piers (substructures) for this bridge appear to be performing well with no significant concerns.

The survey showed the most frequently used tracking activity is to use simple equipment, like a tape measure, and not much advanced technology has been seen used to monitor the slide-in process. A few DOTs indicated concern about the performance of the temporary structure during the slide, such as the differential settlement between the temporary and permanent structure. However, the results indicated that all of the temporary structures performed well, regardless of whether steel or concrete.

Only one state—Michigan—has experience monitoring the substructure. A geometry control plan was developed before the slide-in. During the bridge slide, the pier was instrumented with targets, and the movement was measured with non-contact laser equipment. Both the Poplar Street Bridge and the M-50 Bridge over I-96 were analyzed for performance of their substructures utilizing the finite element approach before their slides started. The analysis focused on the sliding effect, seismic resistance, and barge collide, etc. However, more detailed information was not available since those projects were accomplished by the contractor and the person contacted about the work had left.

Table 4. Summary of survey results for 10 bridges

Year	Bridge ID	State	# of span	Total length (ft)	Total width (ft)	Girder type	Diaphragm type	Pier type	Foundation type	Lateral load application	Sliding system	Temporary structure
2003	I-405 over NE 8th Street	WA	2	328	121.5	Steel plate girders	Steel	Beam column frame	Spread footing	Three locations: diaphragms over pier and abutment	Rollers on guided track	Steel
2005	Hood Canal Bridge	WA	5	605	40	Prestressed bulb-tee girder	Concrete	Beam column frame	Drilled shaft	Six locations: diaphragms over pier and abutment	Rollers	Concrete
2008	Elk Creek Bridge over No.3	OR	3	320.5	38.2	Box beam girder	Concrete	Beam column frame	Drilled shaft	N/A	Stainless steel shoes on Teflon pad	N/A
2011	Ben Sawyer Bridge	SC	13 (5~6 per slide)	1,154	36	Steel plate girders (Approach Spans)	Steel	Multi-column concrete bents (Reused)	Pile footings	N/A	Roller	Inline steel
2011	I-44 over Gasconade River.	MO	6	668	37	Steel plate girders	Steel	Beam column frame (reused)	Spread footing	Seven locations: diaphragms over pier and abutment	N/A	Inline concrete
2013	I-84 (EB & WB)	NY	3	146	60	Double tee	Concrete	Straddle bent abutment	Drilled shaft	Two diaphragms over pier	Stainless steel shoes on unguided Teflon pad	Inline steel
2013	Sellwood Bridge	OR	?	1,100		Steel truss	Truss	Wall pier	N/A	N/A	N/A	Inline steel
2014	Larpenteur Avenue Bridge	MN	2	185.5	61	Prestressed concrete girder	Concrete	Beam column frame	Spread footings	Four locations: diaphragms over pier and abutment	Stainless steel shoes on Teflon pad	Inline steel
2014	M-50 over I-96	MI	2	198	71.25	Box beam girder	Concrete	Beam column frame	Spread footings	Two locations: diaphragms over abutments	Stainless steel shoes on guided Teflon pad	Inline steel
2018	Poplar Street Bridge I-70	MO	5	2,165	112	Steel box girders	Steel	Beam column frame (reused)	Driven pile	Six locations: diaphragms over pier and abutment	N/A	None

3.3 Conclusions from Survey Results

Although a significant amount of valuable information was collected from the survey, it appears the performance of the substructure on multi-span bridges during the slide-in is still a new topic and that not a lot of research work has been conducted on it. The questions that could be answered through the survey were relatively basic, and many questions were left unanswered, including questions surrounding the following topics:

- Drawbacks and advantages of pushing and pulling
- Drawbacks and advantages of two- and four-point pushing/pulling
- Efficiency of steering control during the slide to prevent binding with four support points
- Lateral flexural stress level of continuous girders at piers
- T-pier performance during the slide-in process, etc.

CHAPTER 4. IDENTIFICATION OF DESIGN AND CONSTRUCTION DETAILS

Based on conversations with the TAC members during the meetings in June and August 2019, the research team learned that the Iowa DOT was planning to build a multi-span bridge using the SIBC method. The details of this bridge had not been decided by the date of drafting this chapter. As one of the objectives of this project, the results from the literature review and survey were expected to offer some immediately implementable design recommendations for the upcoming project.

Based on the results from the literature review and survey, the following conclusions can be made with regard to the practical and usable design guidance:

- For most of the bridges with two to five spans, the whole superstructure was usually built continuously over the piers and slid simultaneously onto the permanent structure. For bridges with more than six spans, the superstructure was usually divided into units of up to a few spans, and then slid into final position using the SIBC approach. The investigation indicates that the maximum number of spans in each slide that has been performed is six.

- The length of the bridge superstructure that was built utilizing SIBC method could be as long as 2,165 ft. It was found that the total length of the new bridge was usually shorter than the original bridge since the SIBC method required the construction of the substructure for the new bridge under the original bridge without disturbing traffic on the original bridge. The common practice to achieve that is to build the new abutment in front of the original one. The new bridge is usually wider than the original bridge due to the increase in traffic volume.

- Both spread footings and drilled shafts were commonly used for the foundation. The most frequently used substructure type is the beam-column frame pier with a spread footing foundation, although drilled shafts and driven piles were also used. The most commonly experienced challenges for the selection and construction of substructures include limited headroom, influence to the existing substructure, and the large horizontal loading induced by the slide-in process. During foundation installation, the existing bridge response needs to be monitored to assure its stability.

- With respect to the bridge girders, both pre-stressed concrete beam and steel plate girders have been used with SIBC. However, no special consideration for the lateral flexural stress level in continuous girders has been given to the design of the girders in the past. Both steel and concrete diaphragms were used with the SIBC approach without report of an issue. In general, the lateral forces were applied at all of the diaphragms over the abutment and pier. The diaphragms are expected to be designed as a large, rigid member to jack up the bridge; transfer the lateral load to the deck and girders, and place the rollers and sliding shoes in multiple locations to prevent load concentration.

- Both Teflon pad and roller systems have been used with multi-span bridges. For selection of the sliding system, it appears that, when the superstructure for each slide exceeds about 300 ft in length or 50 ft in width, the roller support was commonly used, since a large, heavier superstructure requires a low coefficient of friction on the sliding track to reduce the lateral slide-in force demand. The researchers found that the coefficient of friction for the Teflon pads were usually assumed from 7% to 20%, while, for the roller system, the friction usually assumed was less than 5%.

- Both steel and concrete temporary structures have been used with inline setup. No outline setup had been used for a multi-span bridge. The inline setup slides the superstructure from the temporary structure directly to the permanent structure. Hence, the connection between the temporary and permanent structure is critical. The different settlement between the permanent and temporary structure during the slide-in of the superstructure is usually a concern. A common practice to capture it is to perform a trial slide before the full slide-in to measure the different settlement. It was suggested that the settlement and deflection of the system subject to the full bridge load should be calculated to determine the initial elevation for the temporary support setup. It is also recommended that a moving load analysis should be performed for the temporary support system considering forces developed in the gravity, longitudinal, and transverse directions.

- Usually, the design of bridge foundations do not consider the large horizontal forces induced by SIBC due to pull or push mechanisms. Hence, it is essential to evaluate the capacity of the substructure and foundation before the slide-in. The substructure should be evaluated for the effect of the uplifting force in the pier column and the overturning of the pier structure, the effect of the transverse forces (transverse to the sliding direction), especially for the unguided sliding system, etc.

- It was found that the difference between the applied force and resistance is not constant throughout the slide-in, which may result in binding and uncontrollable drifting. To allow accurate and rapid force control during the move operation, a servo controller is required. Laboratory tests associated with appropriate monitoring are one of the approaches that could be used to measure the difference between applied force and resistance to provide information for both bridge design and construction planning.

- Little field monitoring and analytical simulation has been conducted to investigate pier structure response during the slide-in, creating a large demand for research to fill this gap.

CHAPTER 5. FIELD MONITORING OF IA 1 OVER OLD MAN'S CREEK

The objective of this task was to monitor the construction effects on a bridge and its associated structural elements during slide-in. To achieve this objective, specific monitoring goals were developed as follows:

- Monitor the overall lateral slide force effects on the piers
- Monitor the uplift and overturning effects on the piers caused by the lateral slide forces
- Monitor the temporary work during slide-in operations
- Assess the efficiency, drawbacks, and advantages of the slide-in procedures used

5.1 Bridge Construction and Sliding Process

The IA 1 Bridge over Old Man's Creek southwest of Iowa City was instrumented for field monitoring. The bridge has a length of 300 ft and a width of 47 ft-2 in., with three spans (90 ft, 120 ft, and 90 ft). Figure 6 shows the bridge orientation.

Figure 6. IA 1 bridge orientation

The traffic flow is in the north-south direction and the lateral slide was conducted from east to west. For a better identification of the orientation, a Cartesian coordinate system was established with y in the vertical direction, x in the bridge transverse direction, and z in the traffic direction. As shown in Figure 6, the permanent pier on the south was labeled Pier 1 and the other was labeled Pier 2.

The bridge superstructure consisted of seven rolled steel girders (W40x249 at middle span and W40 x199 at end spans) and an 8 in. reinforced concrete deck, as shown in Figure 7-a.

a) Bridge superstructure

b) Pier 1 permanent structure

c) Pier 1 temporary structure

d) Pier 2

Figure 7. IA 1 bridge construction

The bridge permanent substructure consisted of two wall piers founded on 14 HP 16 x 101 driven piles each, as shown in Figure 7-b. The temporary pier consisted of six 1-ft diameter steel pipe piles capped with a steel beam, as shown in Figure 7-c and Figure 7–d. The permanent piers were nearly identical in size and construction.

Figure 8 shows the equipment that was essential to the slide-in process.

a) Track over the connection between the permanent and temporary piers

b) Sliding track on the permanent pier

c) Sliding shoes

d) Hydraulic jack

Figure 8. Slide-in equipment

As shown in Figure 8-a, a fixed connection between the temporary and permanent piers was achieved by fastening the steel pile cap of the temporary pier into the face of the concrete permanent pier cap. A continuous steel channel was used across the temporary and permanent piers to guide the slide-in, as shown in Figure 8-b. The Hillman Rollers were used, equipped with horizontal guide rollers that allowed them to use the guide channel and to be guided and maintained on the path. Figure 8-c shows the sliding shoes that carried the bridge superstructure. Eight sliding shoes were used at each pier, with each placed between the two adjacent girders under the concrete diaphragm (previous Figure 7-a). Four hydraulic jacks were used, with one at each pier and abutment location (Figure 8-d).

The bridge slide took about 3.5 hours on the afternoon of September 9, 2020. The superstructure was moved 2 to 3 ft during each push, and then the hydraulic jacks were repositioned. At each push location, two to three team members worked to observe the slide-in process, apply the lateral forces, measure the movement, and communicate via walkie-talkies to ensure equivalent pushing at each jack.

At the end of the bridge slide, the field engineer was satisfied with how the slide went. He anticipated it would take roughly another half hour to an hour to complete the slide and was quite pleased with the speed. The field engineer did note a couple of minor setbacks during the slide-in process but stated they were quickly alleviated through the constant communication of the contractor team. He also mentioned that the slide could have been done even more quickly (possibly in 2.5 hours) if the hydraulic jacking points in the jacking channels for the hydraulic rams had been aligned better.

5.2 Instrumentation Plan

The primary objectives for the field monitoring system were to monitor lateral force effects on the piers and temporary works and flexural stresses in the continuous girders. The lateral force effects were monitored to determine if the bridge slide-in was inhibited or if uneven forces were applied during the slide. The pier behavior was monitored for factors such as uplift and overturning effects. In addition, the transition from the temporary structure to the permanent structure was monitored for settlement or movement that has the potential to inhibit a smooth slide onto the abutments and piers. In addition to the pier monitoring systems, superstructure monitoring systems were developed to capture any flexural stresses in the horizontal plane of the bridge deck and continuous girders. Table 5 lists all of the sensors used in the monitoring system.

Table 5. Summary of instrumentations

Sensor type	Quantity	Instrumentation location
Accelerometers	4	Permanent pier cap
Tilt meters	12	Permanent pier cap
Displacement transducer	4	Permanent and temporary piers
HiTec axial strain gauge	20	Steel pile
Extended BDI strain gauge	14	Concrete deck
BDI strain gauge	16	Steel girder

Figure 9 shows the field deployment of the various types of gauges.

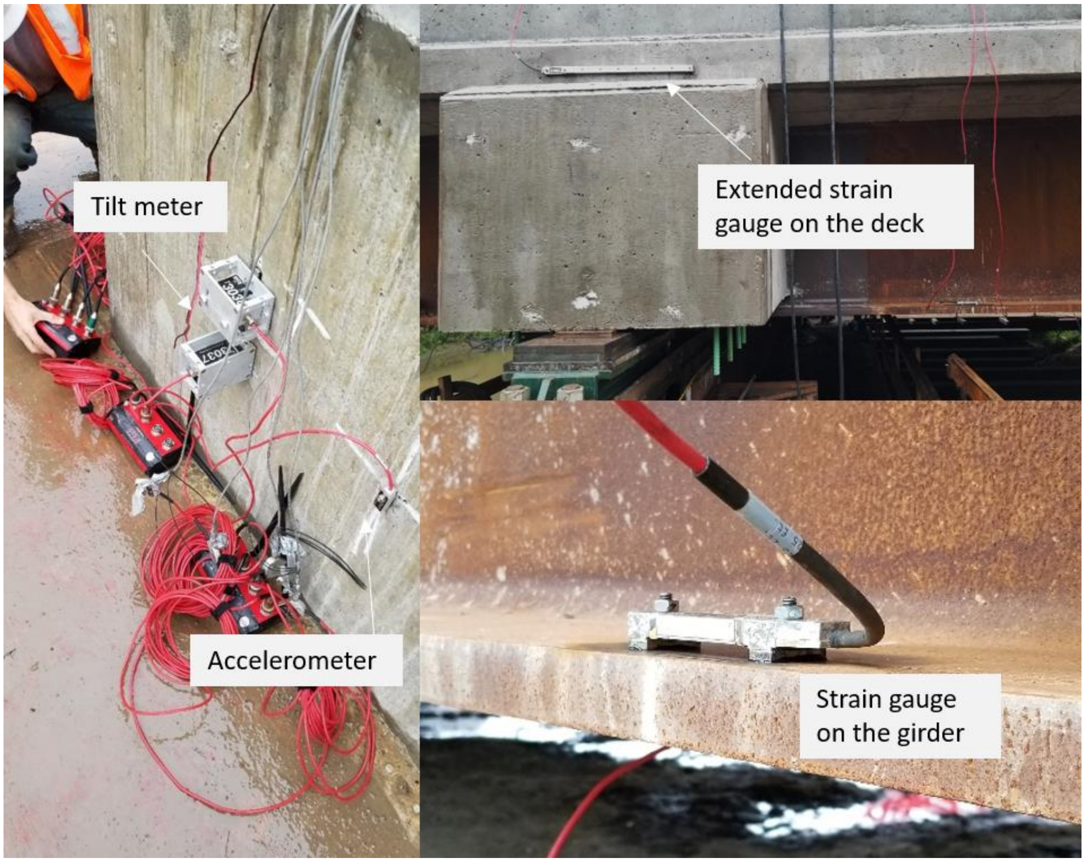
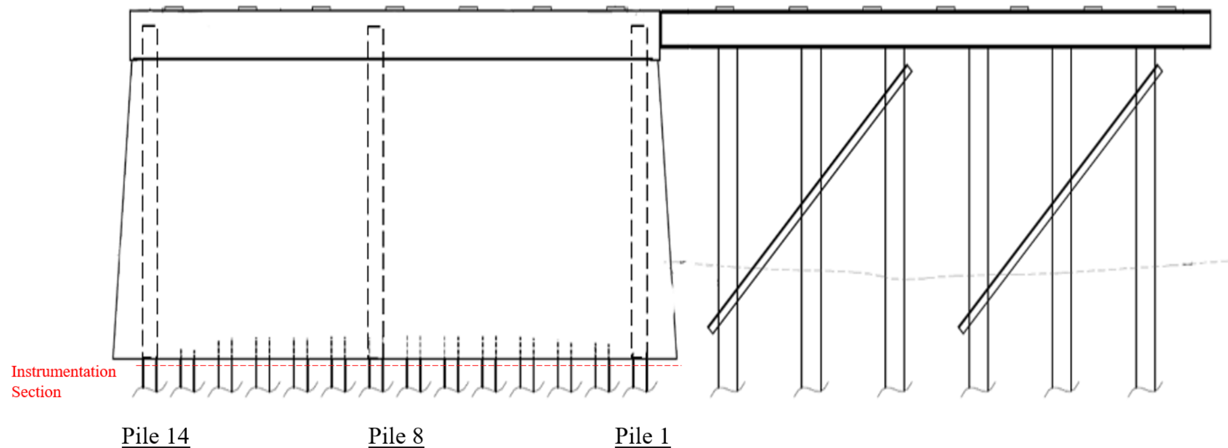


Figure 9. Instrumentation

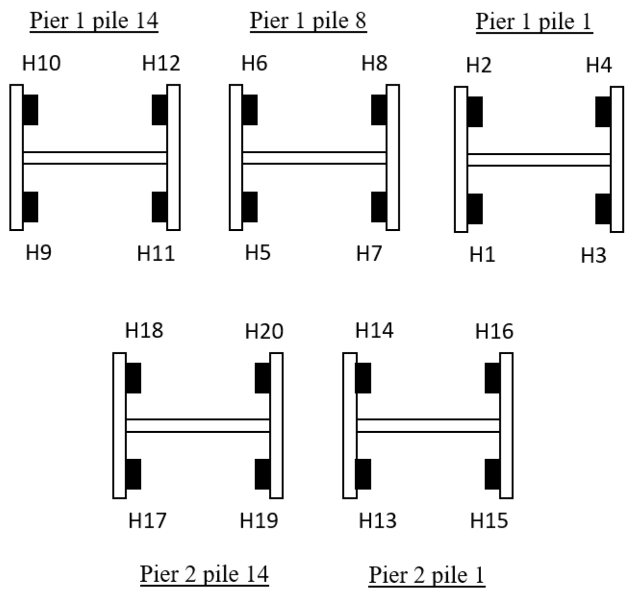
5.2.1 Substructure Instrumentation

The pier instrumentation was designed to capture data to estimate the loads applied to the pier, calculate the movement of the pier cap, calculate the forces in the pier piling, and estimate the effects of binding or racking events. To accomplish this, 20 HiTec axial strain gauges, four accelerometers, 12 tilt meters, and four displacement transducers were installed on the bridge substructure. Piers 1 and 2 on the structure were nearly identical, and there was no significant difference in the superstructure above them. Accordingly, Pier 1 was outfitted heavily with sensing equipment to capture more data. Equipment was similarly installed on Pier 2; however, the number of sensors was fewer and the focus of Pier 2 instrumentation was to provide validation of the results on Pier 1.

HiTec axial strain gauges (H1 through H12) were installed on the piles 6 in. below the pier concrete as shown in Figure 10.



a) Instrumented piles

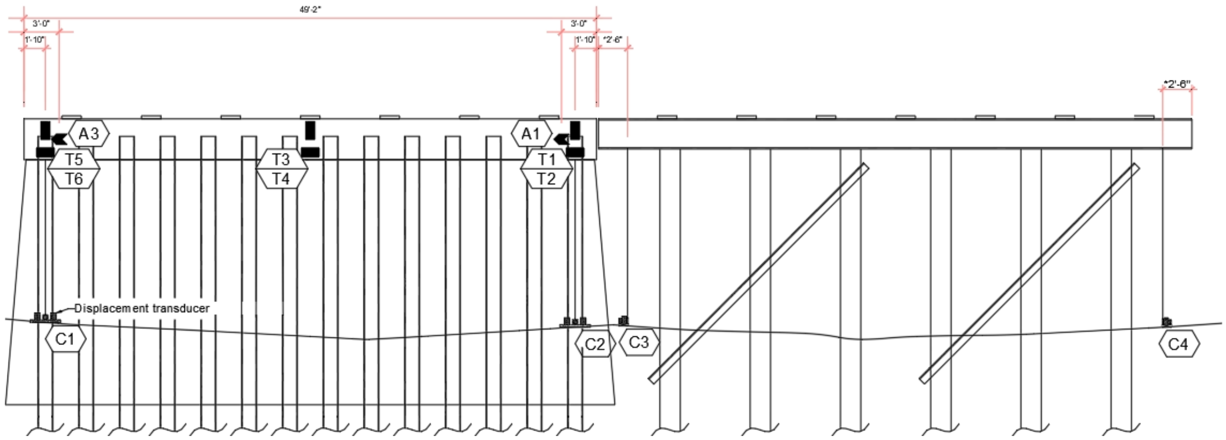


b) Strain gauge on the pile

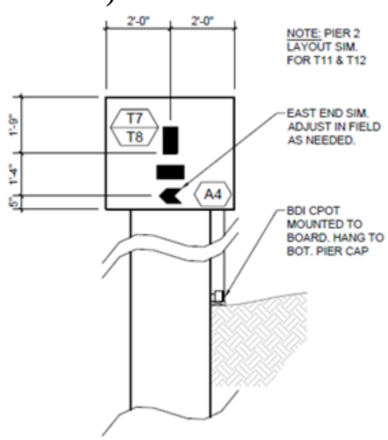
Figure 10. Strain gauges installed on the pile

The gauges were installed on three piles (pile 1, 8, and 14) on Pier 1 and two piles (pile 1 and 14) on Pier 2. Figure 10-b shows the gauge labels for each instrumented section. These strain gauges were arranged in four-gauge groups to monitor strains from bending effects, uplift, and gravity loads. This instrumentation arrangement allows abnormalities from imposed loads to be identified via strain values in the pile flanges and for the reactions in the pile to be calculated.

Figure 11 shows the locations of the accelerometers, tilt meters, and displacement transducers instrumented on Pier 1.



a) Pier front face



b) Pier side view

Figure 11. Pier 1 instrumentation

Four accelerometers (A1 through A4) were used, and all were installed on Pier 1. A1 and A3 were installed on the south face of the permanent pier cap to capture the acceleration in the z (traffic) direction, and A2 and A4 were installed on the east and west sides of the pier cap respectively, to measure the acceleration in the x (bridge transverse) direction.

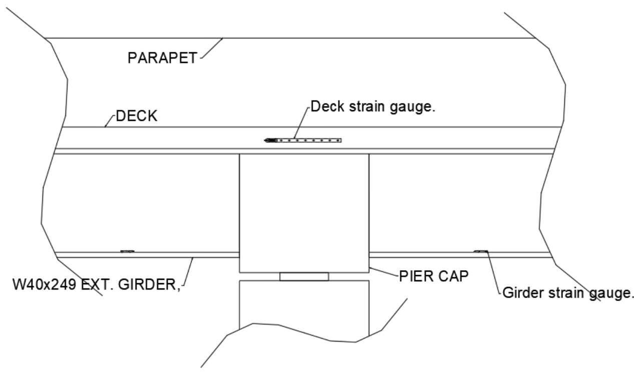
Twelve tilt meters (T1 through T12) were utilized during the monitoring with eight on Pier 1 and four on Pier 2. As shown in Figure 11, for the instrumentation on Pier 1, T1 through T6 were installed on the south face of the pier cap, and T7 and T8 were installed on the side. Pier 2 was instrumented only at the middle of the pier front face and the side of the pier cap with T9 and T10 replacing T3 and T4 and T11 and T12 replacing T7 and T8. Among these tilt meters, T1, T3, T5, T8, T9, and T12 measured the rotation about the x direction, and T2, T4, T6, T7, T10, and T11 measure the rotation in the z direction. These tilt meters were used to monitor the pier caps for rotation.

In addition to the accelerometers and tilt meters, four displacement transducers (C1 through C4) were used to measure the movement in the vertical direction with C1 and C2 installed on the permanent pier and C3 and C4 installed on the temporary structure (previous Figure 11).

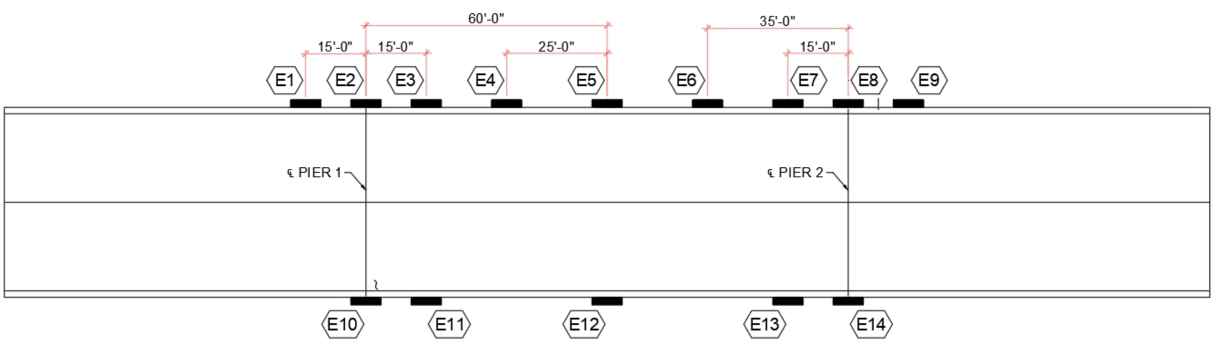
5.2.2 Superstructure Instrumentation

The superstructure was instrumented with a focus on capturing any flexural stress in the deck and girders induced by the lateral slide-in forces. To achieve this objective, the 14 extended BDI strain gauges (E1 through E14) and 16 regular BDI strain gauges (S1 through S16) were installed on the edge of the deck and the girders, respectively.

Figure 12 shows the strain gauge locations on the deck elevation view and the bridge plan view.



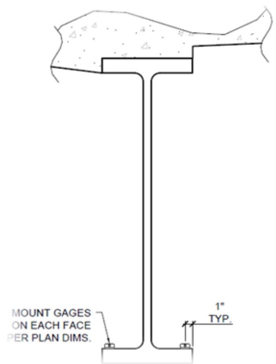
a) Strain gauge on the edge of deck



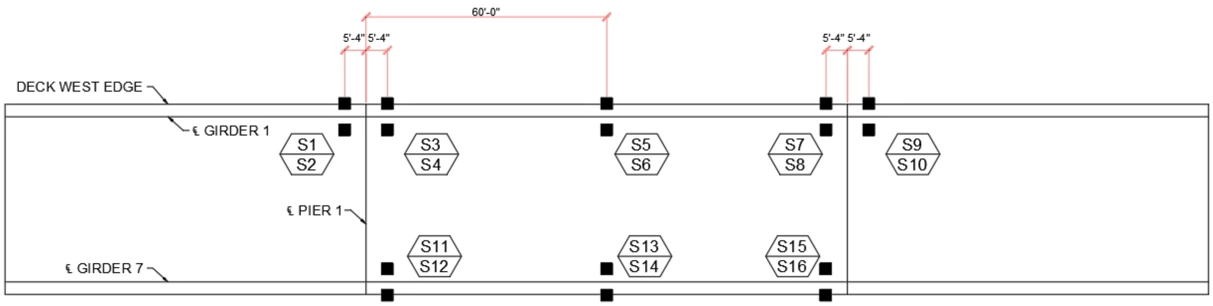
b) Deck strain gauge instrumentation plan view

Figure 12. Extended strain gauges installed on the deck

At each instrumentation location, the deck strain gauges were placed at the middle depth of the deck and used to measure the strain along the traffic direction. Figure 13 plots the BDI strain gauge locations on the girder cross-section view and bridge plan view.



a) Strain gauge on the girder



b) Girder strain gauge instrumentation plan view

Figure 13. Strain gauges installed on the girders

All of the girder strain gauges were installed on the exterior girder at the top surface of the bottom flange. They were placed to measure the strain in the traffic direction.

5.2.3 Data Collection

Over the course of the 3.5-hour bridge slide, data were captured at all locations at a frequency of 20 Hz. Figure 14 shows the setup of the data collection station.

Figure 14. Data collection station

During the slide, a signal loss occurred at approximately 75 minutes into the slide. The data collection was stopped, saved, and restarted. About 15 minutes after this stoppage, data collection was resumed, and the remainder of the slide was captured. It should be noted that the second set of data was offset to the final minute of collected data for all sensors.

During the day of the slide and installation of most equipment, there was a steady rainfall event throughout the day, wetting most of the concrete surfaces. In most cases, the bonding agent was adequate even with this limitation; however, it was noted that, upon removal, some strain gauges were removed more easily than what is typical and, thus, were potentially de-bonded.

5.3 Monitoring Results

The field data collected from the gauges were processed and is presented in the following sections based on gauge type. Each type of data was interpreted with an emphasis on investigating the effect of the lateral slide on the bridge super- and sub-structure.

5.3.1 Acceleration

Although four accelerometers (A1 through A4) were used during the bridge slide-in, only one (A2) indicated significant bridge acceleration that matches the timing of each impulse force/push effort. Figure 15 shows the acceleration data from the A2 accelerometer, which shows the acceleration in the x (transverse) direction.

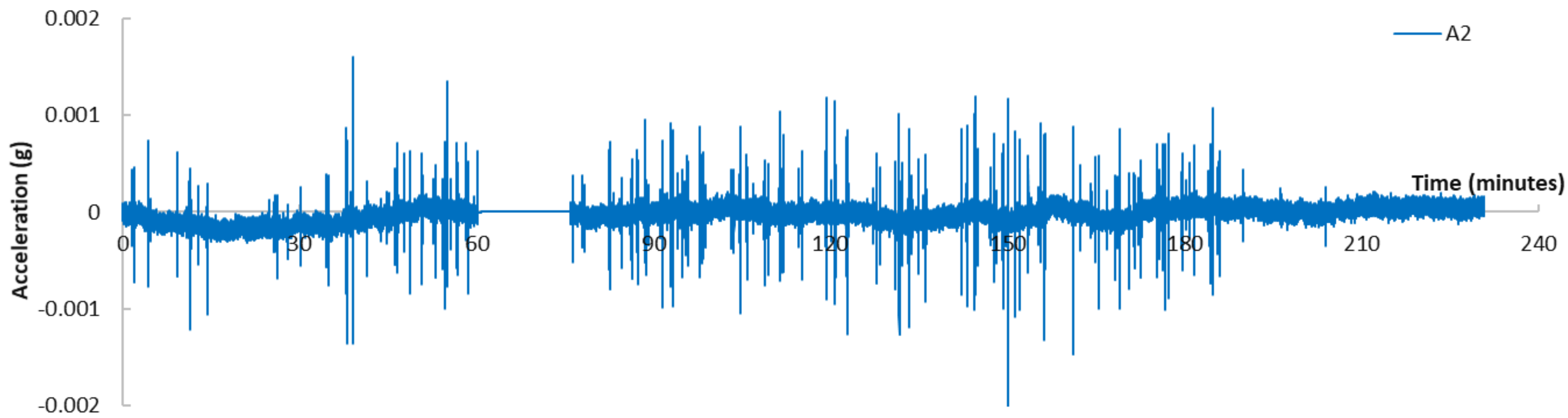


Figure 15. Acceleration data from A2

As can be seen from Figure 15, there are many distinct spikes in the data, corresponding to each jacking event. It is common for long periods of data acquisition for the data to drift. The data were corrected for this drift effect. The results indicated that maximum acceleration in the x direction was 0.002 g. This level of acceleration is similar to the findings by Ridvanoglu (2016) where the pier acceleration during the slide-in of a 198-ft-long, two-span, precast concrete box girder bridge had a maximum measured acceleration due to impulse forces of about 0.0018 g.

Acceleration levels in the other accelerometers (A1, A3, and A4) was quite minimal, and individual peaks could not be identified further reifying the lack of impact. The A2 accelerometer was installed on the east end of the pier cap where it is connected to the temporary piers. It is reasonable to expect this side of the pier to be more sensitive to the slide forces than the other parts of the pier.

5.3.2 Tilt

The tilt data are plotted in Figure 16 through Figure 19. Figure 16 and Figure 17 plot the tilt about the z direction for Pier 1 and Pier 2 (see Section 5.2.1 for gauge locations), respectively. Figure 18 and Figure 19 plot the tilt about the x direction for Pier 1 and Pier 2 (see Section 5.2.1 for gauge locations), respectively.

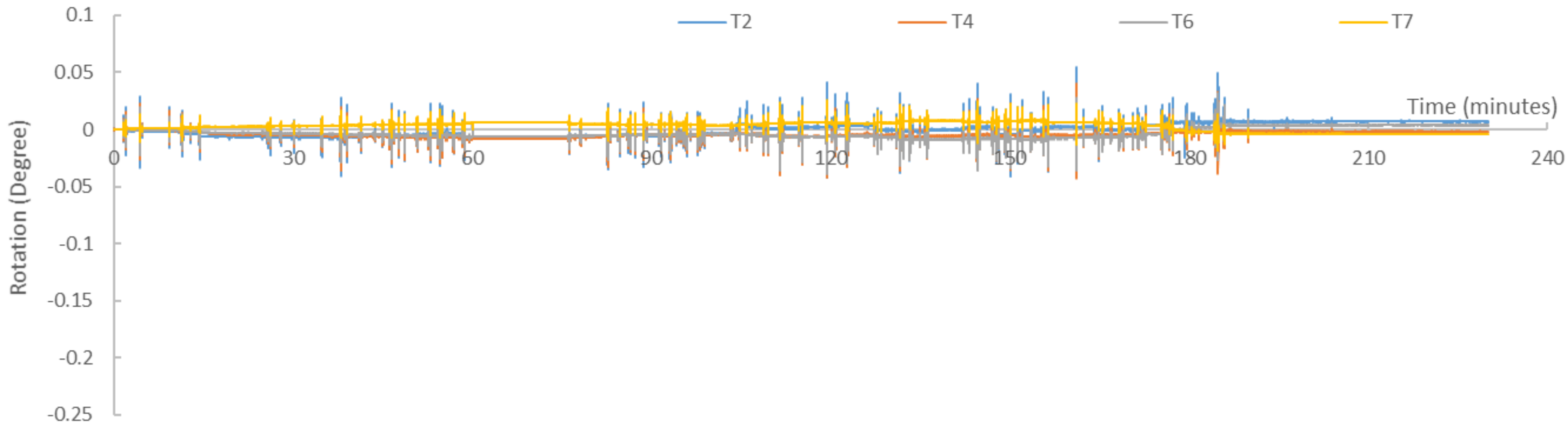


Figure 16. Tilt data from T2, T4, T6, and T7

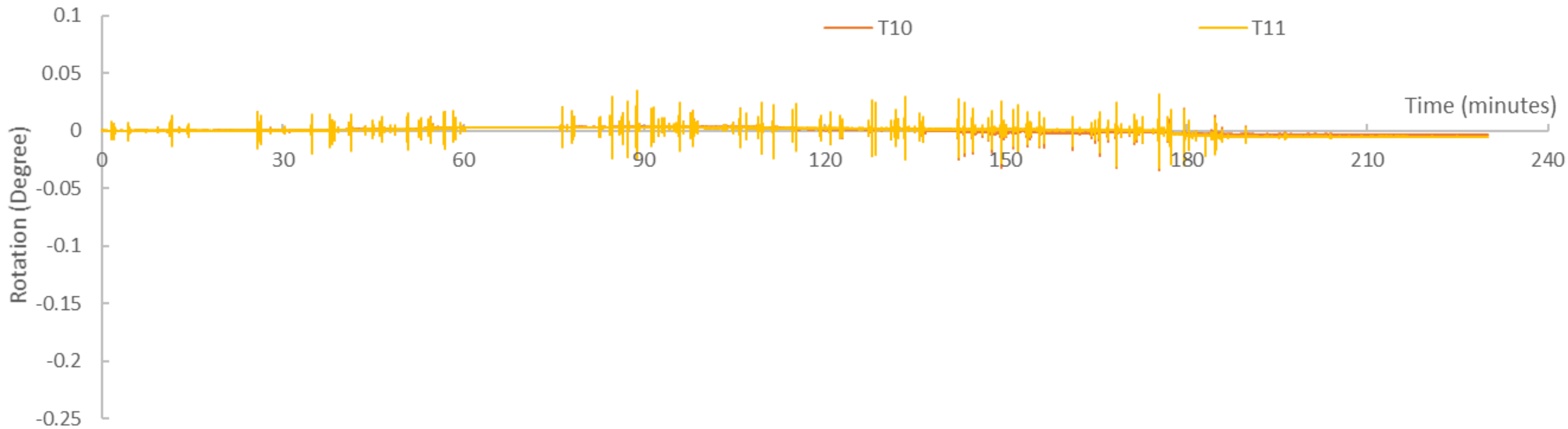


Figure 17. Tilt data from T10 and T11

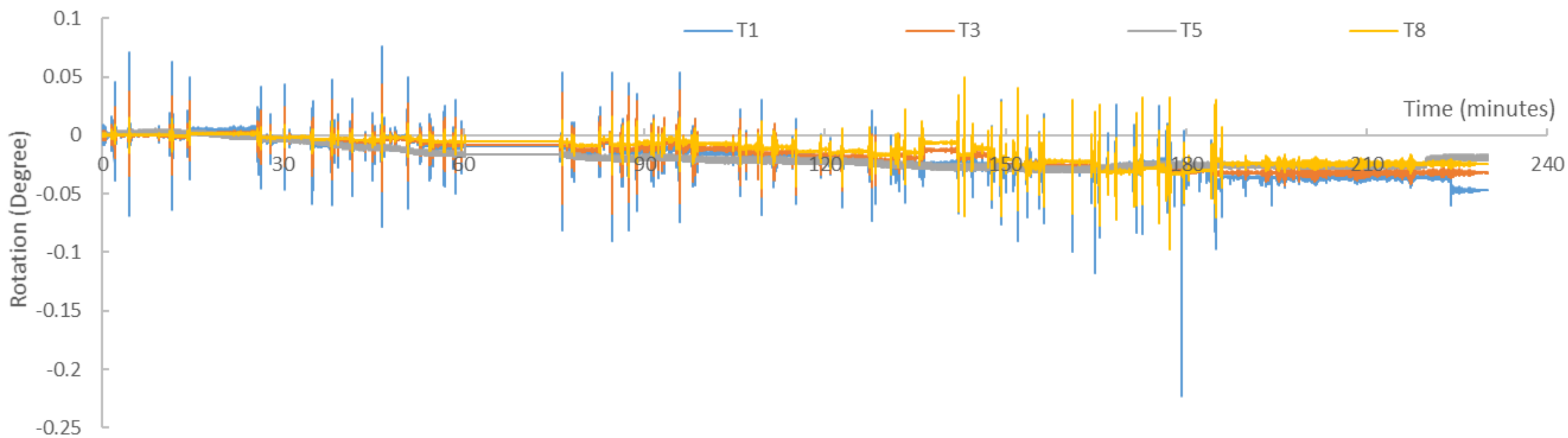


Figure 18. Tilt data from T1, T3, T5, and T8

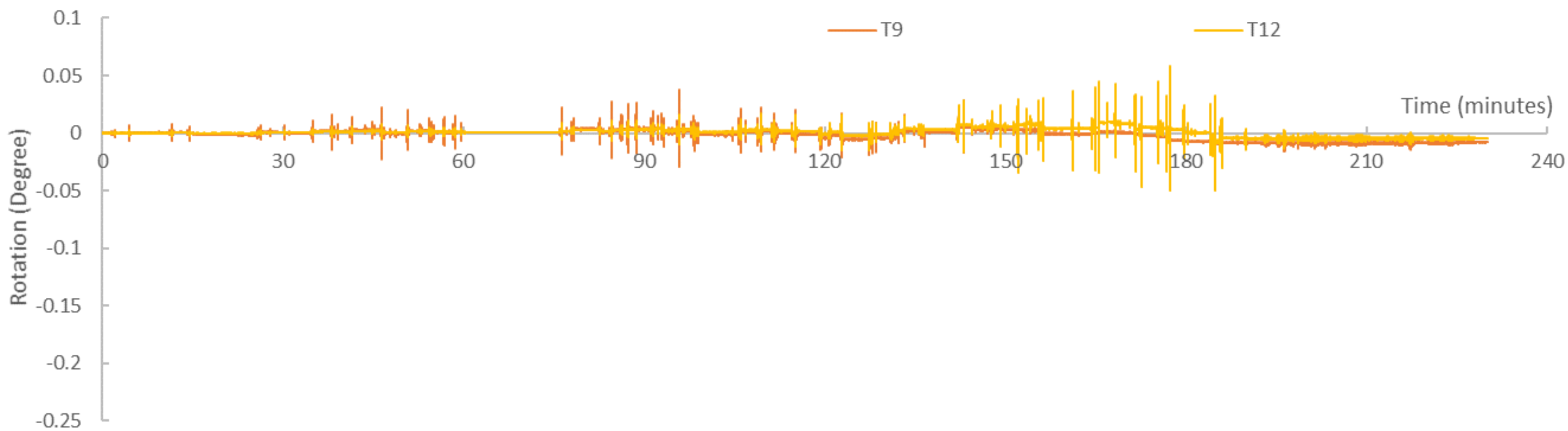


Figure 19. Tilt data from T9 and T12

The results indicate that the maximum tilt caused by the jacking force occurred about the x direction and was approximately 0.2 degrees (from T1). The maximum tilt about the z direction was 0.05 degrees. It was found that all the gauges measuring the tilt in the x direction on Pier 1 showed residual rotation (0.04 degrees) upon completion of the slide (Figure 18). This indicates that a tilt in the z direction remained at the end of the slide due to the slide forces. Such phenomenon was not observed on the gauges measuring tilt about the z direction or on Pier 2. This corresponds to the pier moment of inertia about the z direction being greater than that about the x direction, and Pier 1 has a larger portion above ground than Pier 2, which results in a lower lateral stiffness.

To estimate the horizontal displacement in the z direction at the top of the pier cap, the tilt data about the x direction were used. The pier wall was considered as a cantilever, and a fixed condition was assumed at the bottom of the pier concrete encasement. This assumption aligned with the current Iowa DOT Bridge Design Manual assumption of a fixed condition occurring 6 ft below the ground for concrete encased piles, and the bridge drawing indicated that Pier 1 had about 6-ft embedment into the soil. The displacement and forces in the z direction experienced by Pier 1 were calculated utilizing Equations 1 and 2 (Hibbeler and Kiang 2015):

$$\Theta = \frac{Pl^2}{2EI} \tag{1}$$

$$\delta_{end} = \frac{Pl^3}{3EI} \tag{2}$$

where, Θ is the rotation at the free end, P is the forces in the z direction at the free end, l is the height of the pier (24.5 ft), E is the material Young's Modulus, I is the moment of inertia, and δ is the displacement in the z direction at the free end.

When Pier 1 was subjected to the lateral slide impulse forces, the maximum tilt was approximately 0.2 degrees about the x direction, which results in a maximum displacement of 0.6 in. and a force in the z direction of 400 kips at the top of Pier 1. This result shows similar magnitudes as those in a previously completed study by Aktan and Attanayake (2015). In this case, Aktan and Attanayake found that the maximum pier cap displacement in the bridge traffic direction induced by the lateral slide impulse load was about 0.6 in., which corresponds to a force of 501 kips.

The residual horizontal displacement in the z direction was calculated utilizing the tilt of 0.04 degrees. This resulted in a displacement of 0.14 in. and the force in the z direction of about 80 kips.

5.3.3 Displacement

Figure 20 plots the displacement data for four displacement transducers (see Section 5.2.1 for gauge locations).

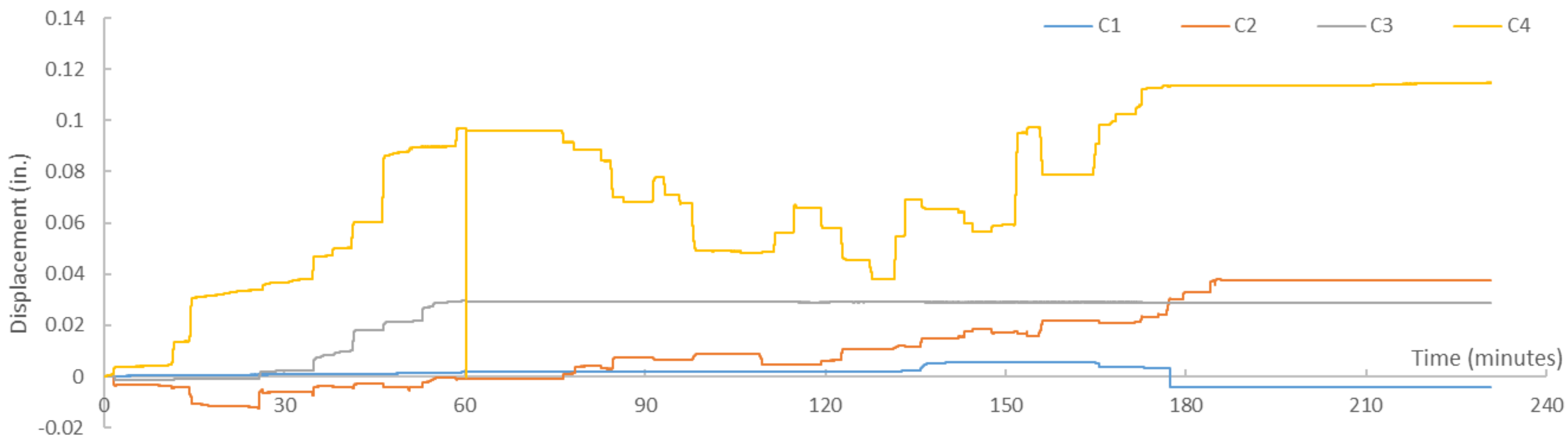


Figure 20. Displacement data from C1, C2, C3, and C4

Positive data indicate an upward movement and vice versa. The results indicate that the permanent pier has less vertical displacement than the temporary structure, which one would expect based on the materials and construction methods associated with each.

The data from the C2 displacement transducer (at the side near the temporary structure) initially showed negative values after the superstructure moved onto the permanent piers, and, as the sliding continued, an uplifting action was observed. Comparing the data from the C1 and C2 displacement transducers, an opposite trend was observed during the second half of the slide-in. This matches the fact that, as more weight from the superstructure was transferred to the substructure, a bending effect about the z direction occurred on the pier.

Both the C3 and C4 displacement transducers showed positive data with a maximum of about 0.1 in. The positive data are reasonable as, when the superstructure moved to the permanent piers, an upward movement occurred on the temporary structure. This movement was quite small and did not create issues during the slide-in process.

5.3.4 Pile Strain

Figure 21 through Figure 25 show the strain data collected from the piles (see Section 5.2.1 for gauge locations). Note that during construction, strain gauge cables for H5, H7, and H14 were damaged, and, thus, no data were collected from these gauges. The maximum strain was measured at pile 1 on Pier 1 (see previous Figure 10 for pile location) at about 285 microstrain, which corresponds to a stress of about 8.3 ksi. The HP piles were Grade 36, with a yield strength of 36 ksi.

Figure 21 through Figure 23 plot the strain for Pier 1.

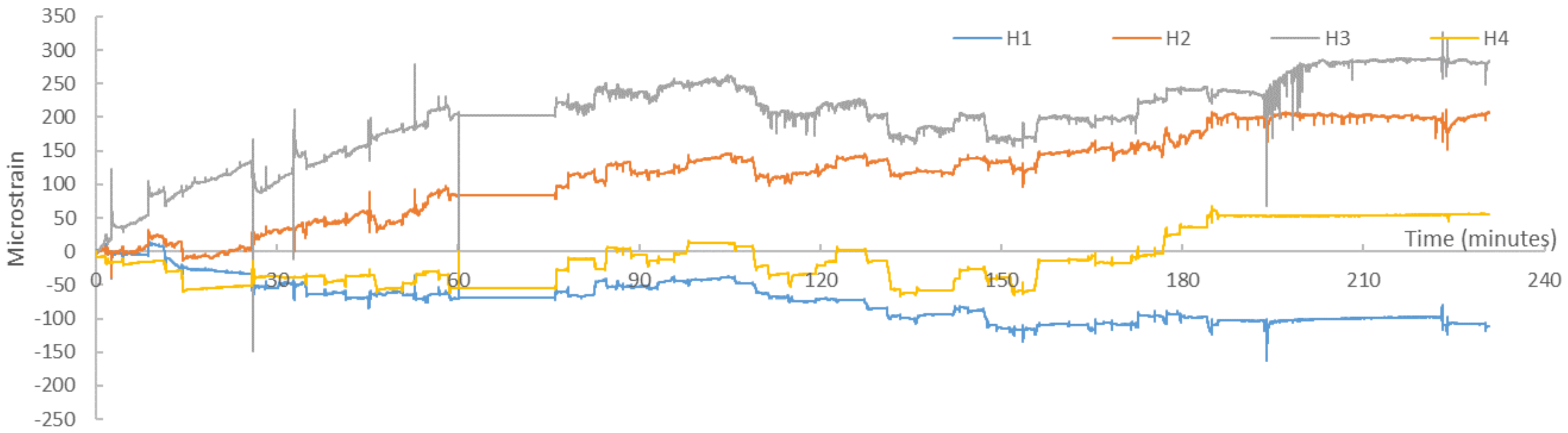


Figure 21. Pile strain data from H1, H2, H3, and H4

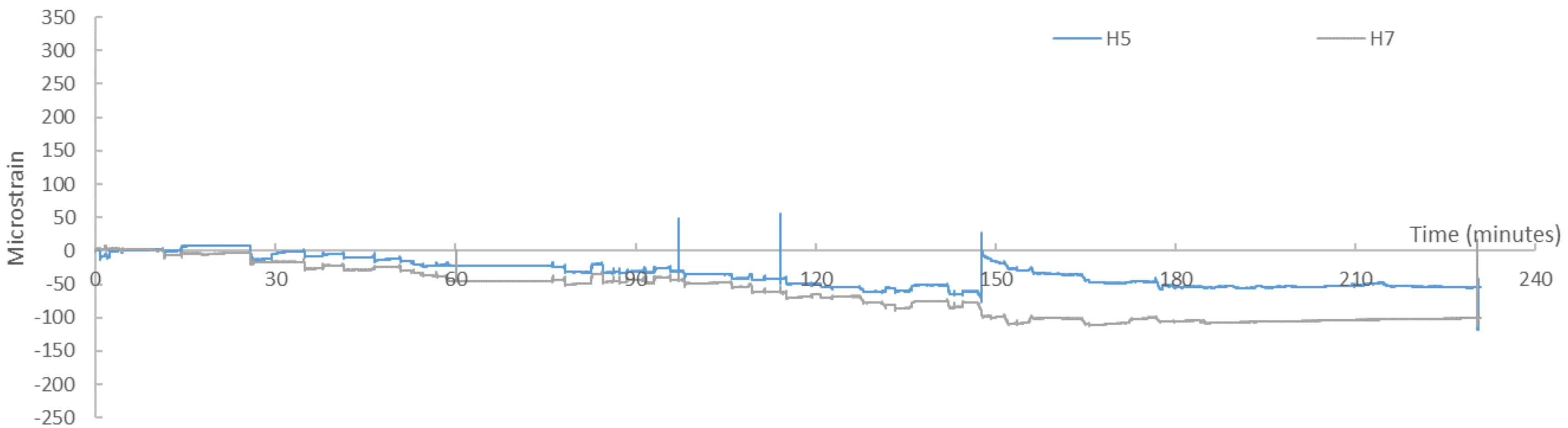


Figure 22. Pile strain data from H5 and H7

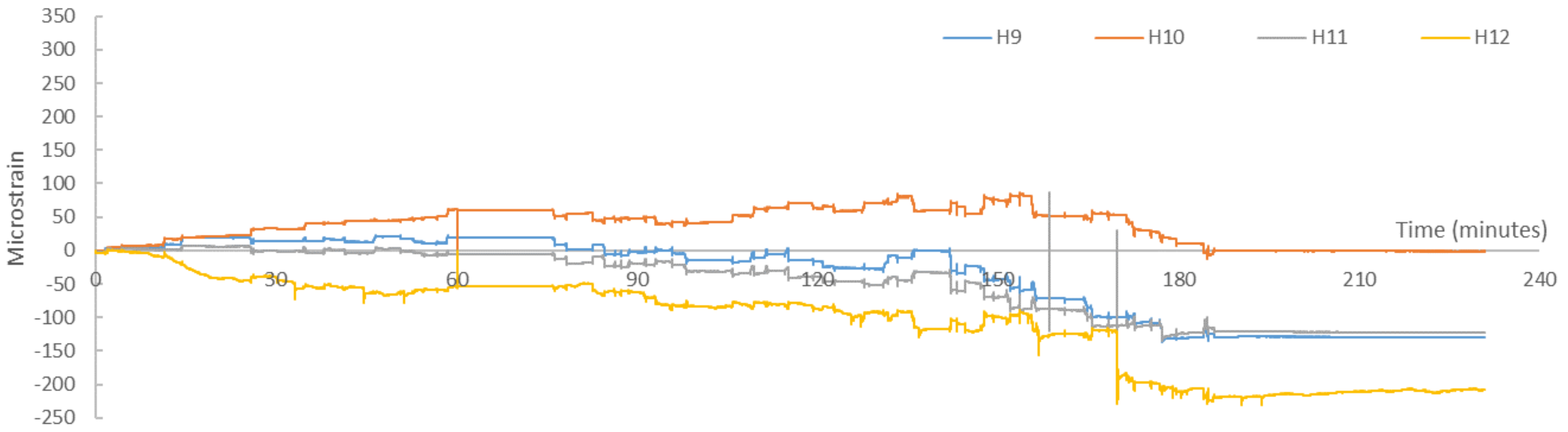


Figure 23. Pile strain data from H9, H10, H11, and H12

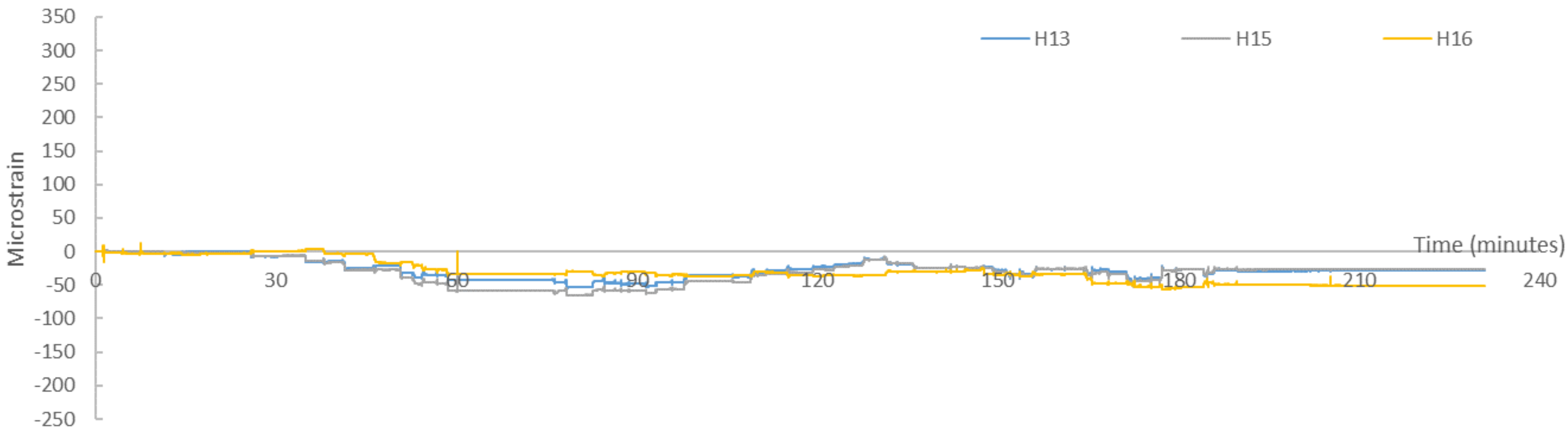


Figure 24. Pile strain data from H13, H14, H15, and H16

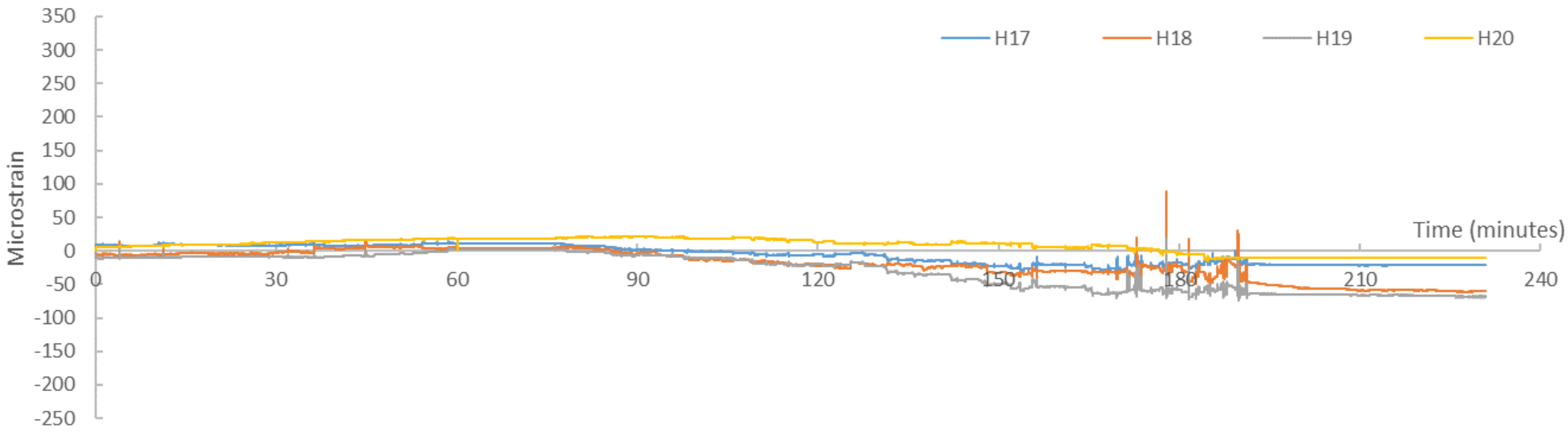


Figure 25. Pile strain data from H17, H18, H19, and H20

Generally, positive strain values were captured from pile 1, and negative strain values occurred on pile 14. This indicates that a moment about the z direction occurred on Pier 1 and an uplifting action occurred on the east side of Pier 1, which shows an agreement with the displacement results. Comparing these data to those collected from Pier 2, the results indicate that the pile strain measured from Pier 2 were small (less than 70 microstrain).

The strain data collected from each pile were further processed to provide axial force, bending, and warping torsion forces at the instrumentation section of the pile. Equation 3 (from Hibbeler and Kiang 2015) was utilized to calculate these loads.

$$\varepsilon = \frac{P_{axial}}{EA} + \frac{M_X y}{E_X I_X} + \frac{M_Z y}{E_Z I_Z} + \varepsilon_{torsion} \tag{3}$$

where, ε is the strain at the instrumentation location, P_{axial} is the axial force on the pile, y is the distance from neutral axis to the strain measurement location, and X and Z are in the global coordinates as shown in the previous Figure 6.

Table 6 presents the results from the calculation.

Table 6. Moment and axial forces acting on the selected piles

Gauge location	Gauge ID	Residual strain after sliding (microstrain)	Resulted force/moment component	Resulted force/moment
Pile 1, Pier 1	H1	-98	P_{axial} (kips)	95
	H2	200	M_X (kips-in.)	-101
	H3	285	M_z (kips-in.)	86
	H4	50		
Pile 1, Pier 2	H9	-120	P_{axial} (kips)	-99
	H10	0	M_X (kips-in.)	94
	H11	-120	M_z (kips-in.)	33
	H12	-216		
Pile 14, Pier 2	H17	-20	P_{axial} (kips)	-33
	H18	-55	M_X (kips-in.)	0
	H19	-65	M_z (kips-in.)	27
	H20	-10		

Given the four unknowns in Equation 3, P_{axial}, M_X, M_Z, and $\varepsilon_{torsion}$, four strain measurements are needed at each instrumented section. Because H5, H7, and H14 were damaged, only the instrumented section that had data for all four strain gauges was calculated for the moments and axial forces.

The results indicated that an uplifting force of about 95 kips occurred on the Pier 1 pile 1. The same behavior was not observed on Pier 2, and both exterior piles (pile 1 and pile 14) on Pier 2 were subjected to downward axial forces. The calculated results indicate that the moment about the x direction (M_x) at the base of Pier 1 ranged from 94 to 101 kip-in. Comparing this to the moment generated by the forces at the top of pier cap in the z direction (80 kips) with a lever arm of 24.5 ft (pier height) (see Section 5.3.2), these M_X values are quite small. This indicates that the assumption of a fixed boundary at the base of the pier is not accurate and is likely lower in the pile on the pile section. The moment about the z direction (M_z) of 27to 86 kips-in. is also minimal.

5.3.5 Deck Strain

Rainfall was occurring during installation of the deck strain gauges. These conditions are not conducive to adhering the strain gauges to the deck, and, while removing the strain gauges after completion of the slide, it was observed that several strain gauges had become de-bonded. Because of this, strain gauges E3, E4, E5, E7, E11, and E12 did not measure significant data. Figure 26 and Figure 27 plots the strain data collected for the remainder of the gauges near Pier 1 and Pier 2, respectively (See Section 5.2.2 for the gauge locations).

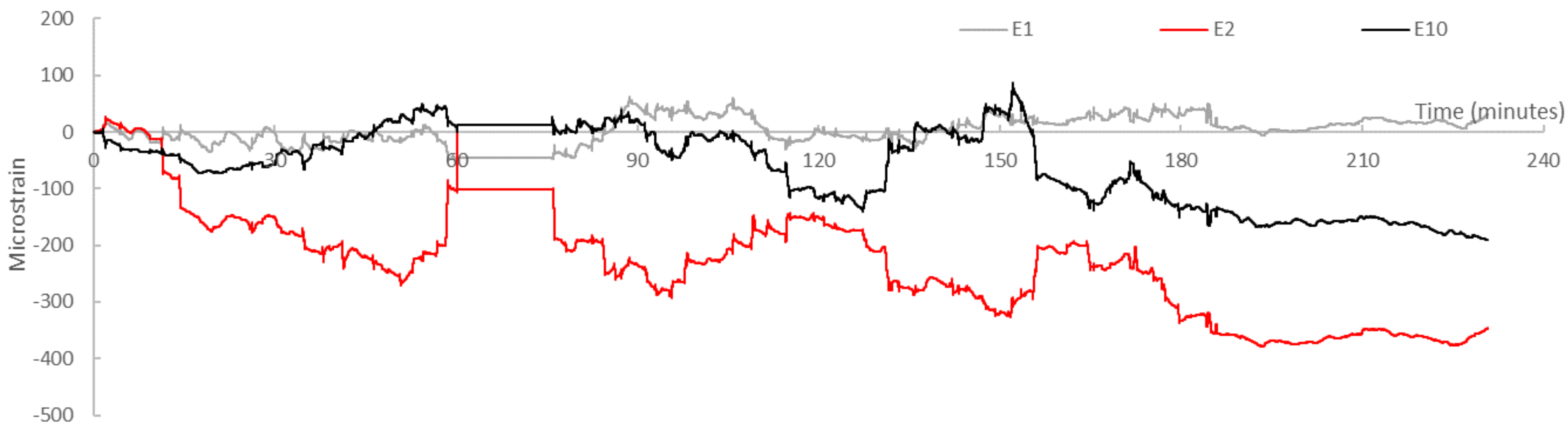


Figure 26. Deck strain data from E1, E2, and E10

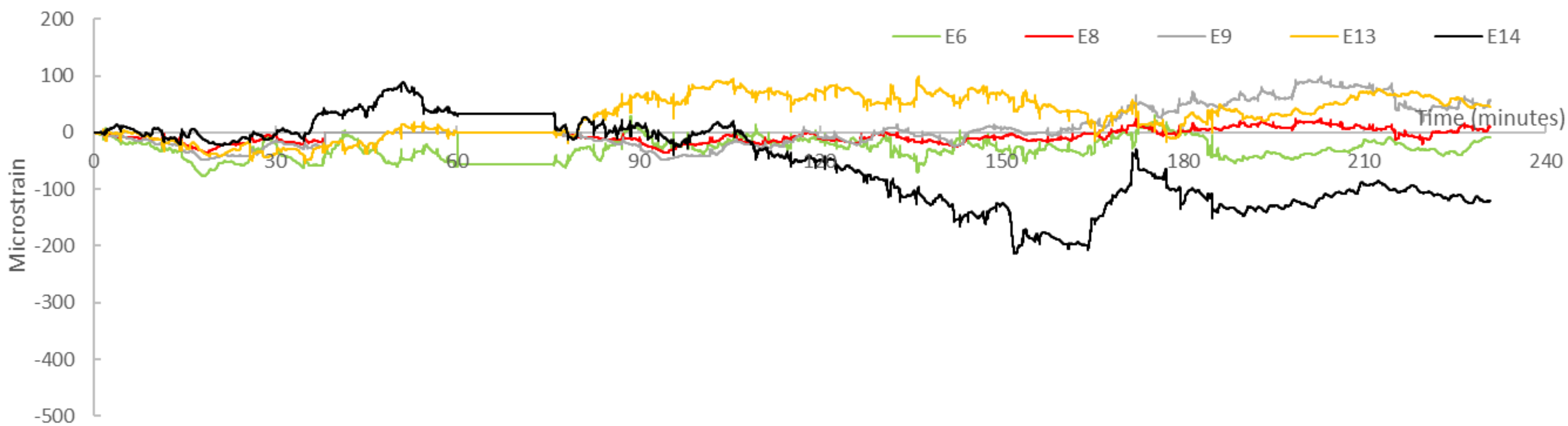


Figure 27. Deck strain data from E6, E8, E9, E13, and E14

For the gauges near Pier 1, the strain data collected from E2 and E10 showed an opposite trend. This indicates that a flexural moment occured on the deck near Pier 1. Although the data from E8 and E14 (near Pier 2) also indicated a similar flexural bending, the strain magnitude was comparatively small.

5.3.6 Girder Strain

Figure 28 through Figure 30 plot the strain data collected from the girder stain gauges. These gauges were installed on the top surface of the bottom flange of the girders (see Section 5.2.2 for the gauge locations). Some strain gauges (S4, S5, S6, S8, S13, and S14) de-bonded due to the wet surface, and, thus, no strain data were obtained.

After a careful investigation of the girder strain data, no conclusions with respect to the superstructure flexural behavior from these girder strain data could be made. A deeper study such as an analytical analysis/finite element study, could be performed to better interpret this data.

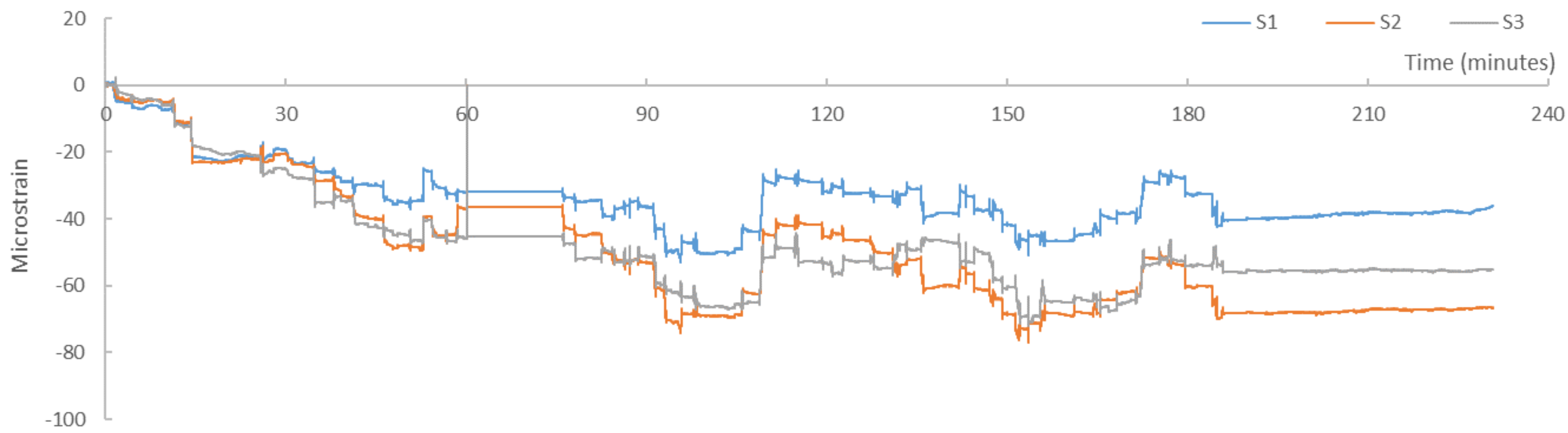


Figure 28. Girder strain data from S1, S2, and S3

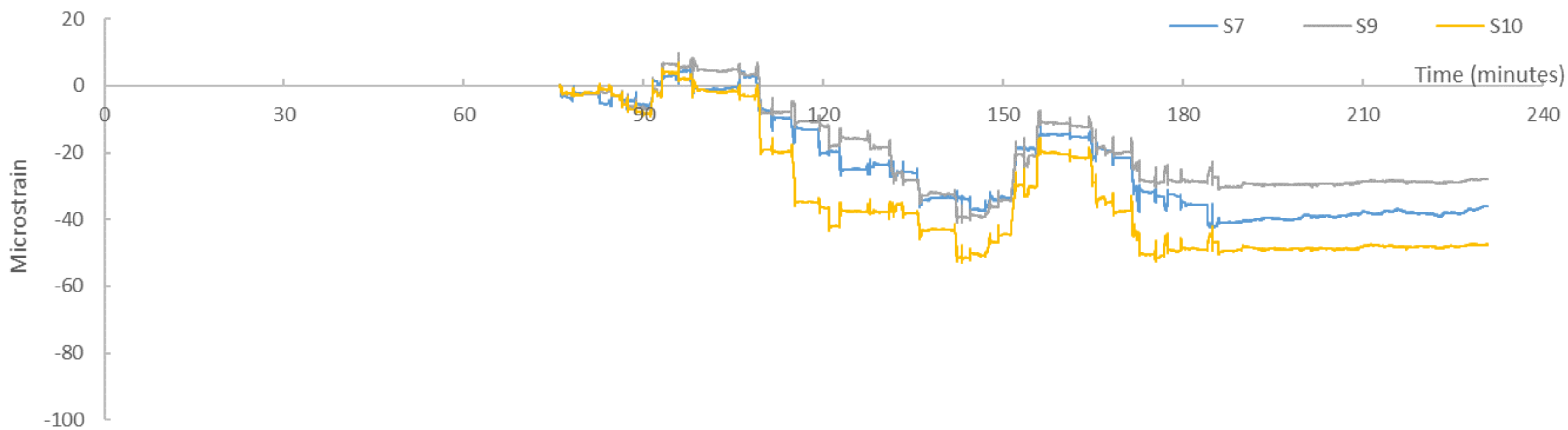


Figure 29. Girder strain data from S7, S9, and S10

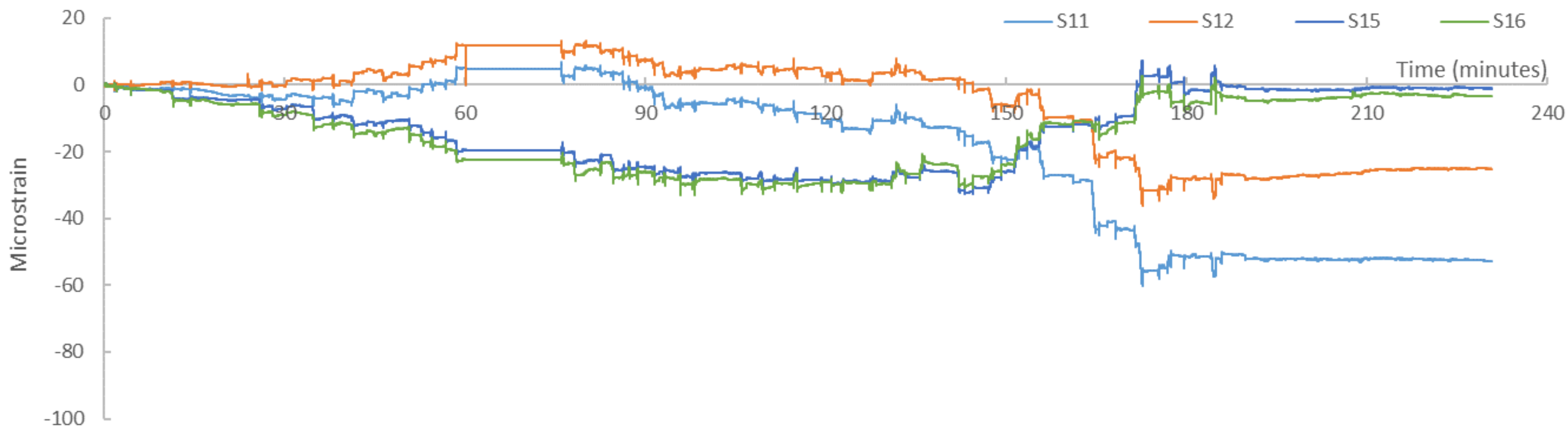


Figure 30. Girder strain data from S11, S12, S15, and S16

5.4 Conclusions from Field Monitoring

The general findings from the field monitoring work can be summarized as follows:

- The slide-in procedure worked well for the multi-span bridge with respect to the steel girder superstructure and the piers. No noteworthy response from the substructure was observed during the slide-in, and no visible signs of distress (e.g., cracking) were observed on the concrete deck or piers. No indications of significant binding or restrictions were observed during the slide-in process.

- The field monitoring results indicate that flexural bending (about the Z direction) of the superstructure on the horizontal plane occurred during the slide-in. However, the deck strain data were minimal, and the resulting forces were inconsequential to the structure. The superstructure consisting of the steel girders and concrete diaphragms performed well during the slide-in.

- Greater strains were measured at the pile strain gauge locations. Even so, the resulting forces were well below the maximum allowable forces. The residual axial and moment forces were low in comparison to capacity. An uplifting action was captured on Pier 1.

- A rough calculation indicates that the greatest forces in the z direction induced by the impulse pushing load experienced at the top of the pier was about 400 kips, with approximately 80 kips of residual force after the slide.

- In general, Pier 1 had larger responses than Pier 2 in both the longitudinal (z) and transverse (x) directions of the bridge. This could be explained by multiple reasons, such as the different embedment heights, different coefficients of friction, or uneven distribution of the weight, etc. A further investigation using analytical methods, such as finite element modeling, is needed to quantify the effect from each parameter.

CHAPTER 6. PROPOSED ADDITIONAL WORK FOR PHASE II

Although a significant amount of valuable information was collected through the literature review and the state DOT survey, many questions remain unanswered. Therefore, additional work is recommended for future study. Further evaluation of structural performance, particularly on the pier and foundation components subject to the slide-in process should be conducted—experimentally and analytically—as a continuation of the project, as was mentioned in the original project proposal.

The results of this work should provide confident validations of the details proposed for the slide-in of a multi-span bridge as was used for the bridge project monitored in the field for this work. As a result of these research results, the implementable ideas and solutions can be carried out and design guidance can be developed.

The objectives of the additional work proposed for Phase II are to investigate the performance of the substructure on the multi-span bridge during lateral slide-in construction and come up with design guidance to provide ideas and solutions for the various questions related to the performance of the substructure and other superstructure connection details. Questions that remain unanswered include those surrounding the following topics:

- Drawbacks and advantages of pushing and pulling
- Drawbacks and advantages of two- vs four-point pushing/pulling (i.e., pushing only at the abutments vs. pushing at all abutment and pier locations)
- Lateral flexural stress levels of continuous girders at the piers
- Performance of different types of piers (including T-piers, beam-column frames, etc.) during the slide-in process
- Effect of the uplifting force in the pier column and in overturning of the pier structure
- Effect of transverse forces (transverse to the slide-in direction)
- Behavior of steel and concrete diaphragms
- Efficiency of steering control during the slide to prevent binding with four support points
- In-depth study of lap-splice strength development for closure pour applications

The following tasks are recommended for Phase II research work:

- Laboratory evaluation
- Finite element analysis/simulation
- Development of recommendations for design and construction

REFERENCES

ABC-UTC. 2019. Accelerated Bridge Construction (ABC) Project Database. Retrieved April 25. http://utcdb.fiu.edu/.

Aktan, H. and U. Attanayake. 2015. *Research on Evaluation and Standardization of Accelerated Bridge Construction Techniques: Part I and Part II*. Western Michigan University, Kalamazoo, MI.

Bhajandas, A., J. Mallela, and S. Sadasivam. 2014. *New York Demonstration Project: I-84 Bridge over Dingle Ridge Road Replacement using Superstructure Slide-In Technology*. Federal Highway Administration, Highways for LIFE program, Washington, DC.

Hibbeler, R. C. and T. Kiang. 2015. *Structural Analysis*. Pearson Prentice Hall, Upper Saddle River, NJ.

Hwang ,J. S., K. C. Chang, and G. C. Lee. 1990. Quasi-Static and Dynamic Sliding Characteristics of Teflon-Stainless Steel Interfaces. *Journal of Structural Engineering*, Vol. 16, No. 10, pp. 2747–2762.

IDOT. 2011. *Bridge Condition Report: Procedures & Practices*. Illinois Department of Transportation, Bureau of Bridges and Structures, Division of Highways, Springfield, IL.

Kuntz, G. and D. Heckman. 2019. *Missouri DOT's Poplar Street Bridge Lateral Slide*. Webinar slides. Accelerated Bridge Construction-University Transportation Center, Florida International University, Miami, FL.

Phares, B., S. Mousavi, and Y. "J." Deng. 2019. *Construction of New Substructures Beneath Existing Bridges*. Bridge Engineering Center, Iowa State University, Ames, IA. https://intrans.iastate.edu/app/uploads/2019/05/new_substructures_beneath_existing_bridges_w_cvr.pdf.

Ridvanoglu, O. U. 2016. Developing Standard Procedures for Structural Aspects of Slide-In Bridges in Accelerated Bridge Construction (ABC). MS thesis. Western Michigan University, Kalamazoo, MI.

Ridvanoglu, O., U. Attanayake, and H. Aktan. 2017. Monitoring during Lateral Bridge Slide. *Transportation Research Record: Journal of the Transportation Research Board*, No. 2630, pp. 23–32.

Shutt, C. A. 2013a. Accelerated Bridge Construction: Sliding and Rolling Bridge Solutions – Part 1. *ASPIRE: The Concrete Bridge Magazine*, Winter, pp. 21–23.

Shutt, C. A. 2013b. Accelerated Bridge Construction: Sliding and Rolling Bridge Solutions – Part 2. *ASPIRE: The Concrete Bridge Magazine*, Spring, pp. 19–20.

Shutt, C. A. 2013c. Accelerated Bridge Construction: SPMT Solutions. *ASPIRE: The Concrete Bridge Magazine*, Fall, pp. 39–41.

Sellwood Bridge Project. 2019. SellwoodBridge.org: A Project of Multnomah County, Oregon. The Big Move. http://www.sellwoodbridge.org/?p=bridge-move-and-detour-bridge.

UDOT and Michael Baker Corporation. 2013. *Slide-In Bridge Construction Implementation Guide: Planning and Executing Projects with Lateral Slide Method*. Federal Highway Administration, Washington, DC.

Zekkos, A. A., R. D. Woods, and A. Grizi. 2013. *Effect of Pile-Driving Induced Vibrations on Nearby Structures and Other Assets*. University of Michigan, Ann Arbor, MI.

APPENDIX A. MULTI-SPAN BRIDGES CONSTRUCTED USING SIBC

This appendix provides descriptions of the 10 multi-span bridges that were found to have been constructed using the SIBC approach in the US.

2003 Washington I-405 Bridge over Northeast 8th Street

A two-span steel girder bridge (shown in Figure A- 1) was constructed using SIBC to replace a six-span, prestressed concrete girder bridge in Washington in 2003.

WSDOT and HDR

Figure A- 1. I-405 Bridge over Northeast 8th Street in Washington

The new bridge is 328 ft long and 121.5 ft wide with two equal 164 ft long spans. The existing bridge was 293 ft long and 103 ft wide with six spans ranging from 44 to 57 ft in length. It should be noted that the shorter full length on the new bridge is a common characteristic of bridges constructed using the SIBC approach.

The replacement bridge consists of 11 5 ft deep steel I-girders spaced at 11.25 ft with a 9 in. thick cast-in-place (CIP) reinforced concrete deck. The reinforced concrete abutments and four-column interior pier are founded on spread footings.

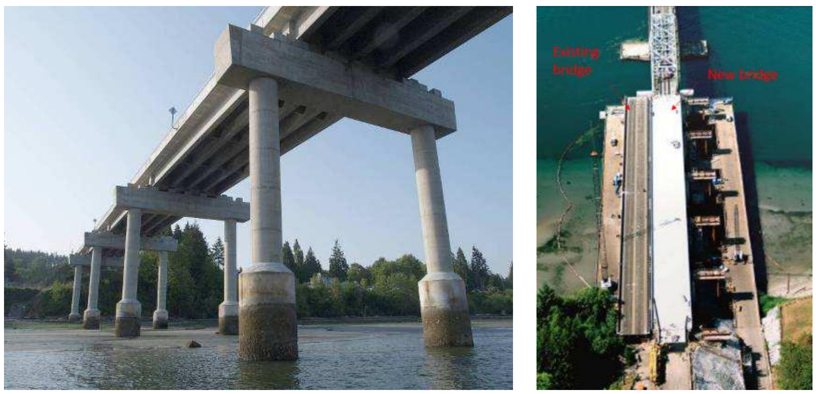
The construction sequence included four stages that allowed all traffic lanes to remain open during replacement of the bridge and also allowed the new two-span superstructure to be laterally rolled into place over a weekend. The contractor constructed the south half of the new bridge on temporary piers south of the old bridge, and then shifted the three eastbound traffic lanes onto the new portion while the north half of the old bridge was removed and rebuilt conventionally.

Next, the three westbound traffic lanes were shifted onto the new north half, and the old south portion was demolished, and substructures were constructed for the south half. On a Friday evening in September, traffic lanes on Northeast 8th Street and I-405 were re-routed, and the bridge was closed. The new south half of the bridge with a self-weight of about 2,200 tons was jacked off its temporary piers and rolled 64 ft north to its permanent location in about 12 hours.

I-405 and westbound Northeast 8th Street traffic lanes were re-opened before noon on Saturday. The remainder of Saturday and Sunday were spent installing permanent bridge bearings, constructing approaches, and striping. All lanes were opened for Monday morning commuters. (ABC-UTC 2019)

2005 Washington Hood Canal Bridge

The east approach spans of the Hood Canal Bridge in Washington were replaced using SIBC in 2005 (see Figure A- 2).



WSDOT

Figure A- 2. Hood Canal Bridge: East approach spans in Washington

The east approach spans provide a fixed link from the shoreline to the floating spans, providing resistance to longitudinal wind and wave forces. The existing six-span steel plate girder bridge was 643 ft long and 30 ft wide. The cross-section consisted of four variable depth (4 ft to 7 ft) girders at 8.5 ft spacing, with a 6.5 in. thick composite concrete deck. Each CIP substructure consisted of a cap on rectangular column, founded on spread footings.

The new bridge width was 40 ft with a total length of 605 ft and five spans with the span length distribution of 125 ft, 125 ft, 122 ft, 122 ft, and 111 ft. The cross-section of the new bridge consists of five W74G prestressed bulb-tee girders, with a 7.5 in. thick CIP concrete deck. Each new CIP substructure consists of a cap on two 6 ft diameter round columns founded on 10 ft diameter drilled shafts. Prefabricated elements included precast abutment backwalls and precast approach slabs. The new bridge has a total weight of about 3,800 tons.

While traffic was maintained on the existing bridge, the contractor built the replacement substructures underneath the bridge, clear of existing piers. Work trestles and temporary supports were then built underneath and beside the existing bridge. The new approach spans were built on the temporary supports on the north side.

At 8 p.m. on a Sunday in August, the bridge was closed, the existing deck was cut at both ends, and jacks were placed under the spans. The old spans were jacked up onto rollers and rolled onto temporary false work by 4 p.m. on Monday. The old spans were then demolished and the precast abutment backwalls were erected.

Multiple synchronized jacks were used to lift the new spans onto rollers. The spans were then rolled into place as a unit at a rate of 5 miles per hour. The new spans were in place by 12 a.m. Tuesday morning. Permanent bearing pads were set at each pier. Finish work was completed and the bridge was re-opened to traffic on Tuesday at 8:40 p.m., for a 49 hour total closure. (ABC-UTC 2019)

2008 Oregon Elk Creek Crossing No. 3 Bridge

The Elk Creek Crossing No. 3 Bridge in Oregon was replaced using SIBC in 2008 (see Figure A-3).

ODOT

Figure A- 3. Elk Creek Crossing No. 3 Bridge in Oregon

The existing reinforced concrete deck girder bridge with steel truss was 340 ft long and 30 ft wide with a pile bent substructure. The new bridge has three spans and is 320.5 ft long by 38.2 ft wide. The three spans are 56.5 ft, 207.5 ft, and 56.5 ft long. The cross-section consists of three 7.5 ft deep steel I-beams spaced at 14.61 ft, with a 10.75 in. thick CIP concrete deck. The substructure consists of CIP concrete caps and columns founded on drilled shafts.

The replacement superstructure was built adjacent to the existing bridge and laterally slid into final position over a weekend. Precast elements consisted of girders, wingwalls, sleeper slabs, and approach slabs. All precast elements were fabricated at the contractor’s yard and transported to the site for installation.

With traffic maintained on the existing bridge, construction was performed in a sequence of constructing a new substructure for the replacement bridge under the existing bridge (CIP drilled shafts, columns, and caps), constructing a temporary substructure for the existing superstructure on one side of the existing bridge, constructing a temporary substructure for the replacement superstructure on the other side of the existing bridge, and constructing the replacement structure complete with railing.

On a Friday evening, the existing bridge was closed to traffic at 8 p.m. with traffic detoured for the two-day closure. Preliminary work included removing the asphalt overlay, bridge railings, and approach slabs. On Saturday, the old superstructure was lifted and slid laterally with bearing pads onto temporary supports using hydraulic jacks mounted on sliding rails. The move took about four hours to complete. Backfill was then placed and the precast wingwalls, sleeper slabs, and approach slabs were installed. (ABC-UTC 2019)

2010 South Carolina Ben Sawyer Swing Bridge

In 2010, a 1,154 ft long multi-span steel bridge was constructed using SIBC in South Carolina (see Figure A- 4).

SCDOT

Figure A- 4. Ben Sawyer Swing Bridge in South Carolina

The original historic two-lane bridge was built in 1945 to connect the towns of Sullivan’s Island and Mount Pleasant over the Atlantic Intracoastal Waterway. The swing-span truss and approach spans were deteriorated and required replacement.

The new swing span was a 640 ton center-pivot-modified Pratt through-truss with top and bottom chords at the same elevation as the existing truss, and with new electrical and mechanical systems. The 7 in. replacement deck consisted of a 2.875 in. thick steel grid with a 4.125 in. thick precast lightweight reinforced concrete composite topping. The cross-section of the approach spans consist of two 5.75 ft deep steel plate girders spaced at 23 ft (with floor beams), with an 8 in. thick lightweight concrete deck.

The new swing span was constructed offsite at the former Navy base in North Charleston approximately two miles from the bridge site. The six approach spans on each end of the swing span were built on temporary false work adjacent to the existing bridge on the south side while traffic was maintained. The approach spans were conventionally constructed with lightweight reinforced concrete decks on steel girders. The existing substructure was rehabilitated.

During the slide-in of the superstructure, the bridge was closed, and the existing approach spans were transversely shifted onto temporary supports adjacent to the existing bridge piers. The six new approach spans on one end were simultaneously pulled 30 ft transversely along horizontal tracks onto the existing piers that had been retrofitted with seismic isolation bearings. The six new spans on the other end were then also pulled into position as a unit. Each approach was moved in approximately 24 hours using post-tensioning jacks with the jack stroke limited to three in. each pull.

Barges then brought the new swing span from its nearby holding location and lifted the existing swing span off its pivot pier. The barges then backed up, lowered the old span, rotated 180 degrees, moved back in, and lowered the new span into position. The old swing span was then barged back to the pier in North Charleston for demolition. The existing approach spans were demolished on their temporary supports adjacent to the new bridge. (ABC-UTC 2019)

2011 Missouri I-44 Bridge over Gasconade River

A six-span bridge on I-44 was constructed in Missouri using SIBC to replace the old bridge in 2011 (see Figure A- 5).

Figure A- 5. I-44 Bridge over Gasconade River in Missouri

The original two-lane riveted plate girder bridge was built in 1955 and was 670 ft long and 34 ft wide. The replacement bridge was the same length. The superstructure end spans are simple spans and the middle four spans are a continuous unit. The superstructure cross-section consists of four Grade 50W steel plate girders at 9.67 ft spacing with an 8.5 in. thick composite concrete deck. The girders in the end spans are 3.5 ft deep, and the girders in the middle unit are 6 ft deep.

The contractor built the replacement bridge and the temporary substructure adjacent to the existing bridge using conventional construction while both traffic lanes remained open on the existing bridge. The bridge was constructed at the same elevation as the existing bridge and supported on sliding bearings to eliminate the need for bearing transitions. The top of the temporary substructure was cast at a constant elevation to facilitate the slide-in.

On May 5, after the new bridge was completed, westbound traffic was shifted to the eastbound bridge. The existing westbound bridge was demolished and the substructure was repaired.

On May 16, the lateral move began at 9 a.m. A standard stainless steel and Teflon sliding surface was used between sliding bearings and the top of the cap. The replacement bridge was slid 45 ft into place using a 70 ton 3 ft stroke hydraulic jack placed at each substructure, with all jacks interconnected to control the differential rate of movement. The slide-in was completed at 7 p.m., requiring a total of 10 hours. After the bridge was in its final location, it was lifted slightly by six jacks in unison at each substructure to transfer bearing from the temporary sliding bearings to the permanent bearings. (ABC-UTC 2019)

2013 Oregon Sellwood Bridge

The 1,100 ft long Sellwood truss bridge was moved to set up a detour bridge in 2013. The truss span was moved on Saturday, January 19. Moving it north created space for the new Sellwood Bridge to be built in the alignment of the old bridge (see Figure A- 6).

Figure A- 6. Sellwood Bridge in Oregon

The 3,400 ton truss span was one of the longest bridge parts ever moved. The age and shape of the truss combined with the curved path of the move made it a highly complex undertaking. The actual move only took about 14 hours, but extra closure days were needed to install road connections at each end of the truss span and complete an in-depth inspection of the detour bridge before it opened to traffic. (Sellwood Bridge Project 2019)

2013 New York I-84 Bridge over Dingle Ridge Road

The I-84 Bridge over Dingle Ridge Road in New York was replaced using SIBC in 2013 (see Figure A- 7).

Bhajandas et al. 2014, FHWA

Figure A- 7. I-84 Bridge over Dingle Ridge Road in New York

The replaced twin steel girder three-span bridges built in 1967 were 140 ft long with an out-to-out width of 33.3 ft. The replacement structures were wider to accommodate three lanes of traffic, a 6 ft left shoulder, and a 12 ft right shoulder to provide for future lane addition and traffic control.

The contractor constructed the replacement superstructures adjacent to the existing structures and slid each superstructure overnight after demolishing the old structure. The replacement structures were also raised by about 2 ft to provide 14.5 ft under-clearance. Additionally, substructure construction of the replacement structures needed to minimize any impact on existing abutments supported on spread footings on fill.

To accelerate construction, the NYSDOT used prefabricated elements for both the superstructure and wall elements and, to the extent practical, readily available innovative bridge designs for rapid renewal. Each superstructure consisted of northeast extreme tee (NEXT) double-tee beams and precast elements. The longitudinal joints between the superstructure elements were closed at the job site using ultra-high-performance concrete (UHPC).

Because the NYSDOT planned to close I-84 to the minimal extent possible, the approach slabs were precast and connected to the superstructure as one unit ahead of the ABC closure period. The gap between the slab and the ground of the end spans was filled with flowable fill so that each slab was fully supported, resulting in each structure being single span. (Bhajandas et al. 2014)

2014 Minnesota Larpenteur Avenue Bridge

In 2014, a 187.1 ft long, 75.8 ft wide, two-span prestressed concrete I-beam bridge was built using SIBC in Minnesota (see Figure A- 8).

MnDOT

Figure A- 8. Larpenteur Avenue Bridge in Minnesota

The existing to replace a four prestressed concrete beam bridge was 185.5 ft long and 61 ft wide with pile-supported substructures. The replacement bridge has four through-lanes, a center-turn lane, wider shoulders and 8 ft wide sidewalk. The cross-section consists of seven 45 in. deep prestressed concrete beams spaced at 11.33 ft with a 9 in. thick CIP concrete deck. The CIP semi-integral abutments were founded on spread footings.

The Larpenteur Avenue Bridge carrying local traffic over I-35E was selected to be replaced using the lateral slide SIBC method. The contractor's team utilized temporary steel pile bents to support the new superstructure in the temporary position adjacent to the existing bridge. While the existing bridge remained in service, the temporary steel pile bents were constructed, and the new bridge superstructure was constructed in the temporary position.

As the deck cured on the new superstructure, the existing bridge was closed and demolished, and the new substructures were constructed. After the new substructure concrete and the new superstructure concrete achieved strength, the new superstructure was pushed into place using hydraulic jacks and bearing pads. (ABC-UTC 2019)

2014 Michigan M-50 Bridge over I-96

The M-50 Bridge over I-96 in Michigan was built using SIBC in 2014 (see Figure A- 9).

Figure A- 9. M-50 Bridge over I-96 in Michigan

SIBC was selected based on user delay costs following the evaluation of the site for SIBC suitability. The project consisted of full structure replacement and improvements to the ramps at the intersection. The existing four-span bridge was 227 ft long and 37.5 ft wide. The new two-span, 198 ft long and 71.25 ft wide bridge includes wide shoulders and two left turn lanes.

The new bridge is a continuous for live load structure with a jointless deck and independent backwalls. The CIP concrete approach slab is supported on a sleeper slab on one end, and the other end is tied to the bridge deck. The approach slab concrete was cast following the move along with a closure pour.

The new superstructure was constructed on a temporary substructure on the west side of the old structure and adjacent to the permanent alignment of the bridge. The temporary substructure consisted of temporary abutments and pier. The temporary substructure was built so that the new abutments and pier were aligned. The piles for the temporary substructure were specified to be at least 20 ft 4 in. away from the old structure.

Two spans of the new structure were slid using jacking locations at the two abutments and the central pier. At the pier and abutments, the sliding shoes were attached to half-depth precast diaphragms. The precast diaphragms were placed on the sliding tracks attached to CIP temporary bents. The temporary bents were supported on temporary steel piles. The box beam girders were placed on the half-depth precast diaphragms, and the remaining depth of diaphragms was CIP following the move. (Aktan and Attanayake 2015)

2018 Missouri/Illinois Poplar Street Bridge

The Poplar Street Bridge was a 50-year-old, 2,165 ft long, five-span structure that carries I-55 and I-64 over the Mississippi River in downtown St. Louis, connecting Missouri and Illinois. MoDOT was the lead state on this joint project with IDOT (see Figure A- 10).

Kuntz and Heckman 2019, ABC-UTC

Figure A- 10. Poplar Street Bridge between St. Louis, Missouri and Illinois

The bridge has twin eastbound and westbound superstructures consisting of two variable depth steel box girders with orthotropic steel decks on a shared substructure. A unique aspect of the project was the slide-in of the existing eastbound superstructure in lieu of a traditional widening.

Based on a review of highway bridge replacements to date, this project is the largest lateral bridge slide by deck area and the second longest lateral slide by bridge length in the US. The eastbound superstructure was successfully slid 9 ft to the south onto widened piers in March 2018 over the course of 2.5 hours.

The eastbound and westbound superstructures were then connected together using a concrete deck on a stringer-floor-beam type cross-frame system, which added redundancy and improved the performance of the structure. (Kuntz and Heckman 2019)

APPENDIX B. COMPLETED SURVEY QUESTIONNAIRES FOR MULTI-SPAN SBIC BRIDGES

1. Basic information			
1.1 Bridge ID	I-405 over NE 8th Street	1.2 State	WA
1.3 Project year	2003	1.4 Total number of spans	2
1.5 Span length (ft)	164'-164'	1.6 Total length (ft)	328'
1.7 Total width (ft)	121.5'		

2. Sliding system	
2.1 What is the maximum number of the spans in each slide?	2
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Hydraulic jack at each diaphragm over pier and abutment	
2.4 Sliding system (Over pier): Roller on guided track	
2.5 What was the friction level? Not sure	
2.6 Type of steering control system: Not sure	
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure	

3. Substructure near pier			
3.1 Foundation type	Spread footing	3.2 Pier type	Beam-column frame
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? None			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? None			
3.5 Temporary structure type: Concrete column with steel cap			
3.6 Was there significant deformations observed on the temporary works during sliding operations? Not sure			

4. Superstructure over pier			
4.1 Girder type	Steel I-girder	4.2 Diaphragm type	Steel
4.3 How was the performance of the diaphragm over piers? Not sure			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?			

5. Investigation
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Not sure
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. Not sure
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. Not sure

1. Basic information			
1.1 Bridge ID	Hood Canal Bridge	1.2 State	WA
1.3 Project year	2005	1.4 Total number of spans	5
1.5 Span length (ft)	125'+125'+122'+122'+111'	1.6 Total length (ft)	605'
1.7 Total width (ft)	40'		
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			5
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Hydraulic jack at each diaphragm over pier and abutment			
2.4 Sliding system (Over pier): Rollers			
2.5 What was the friction level? Not sure			
2.6 Type of steering control system: Not sure			
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure			
3. Substructure near pier			
3.1 Foundation type	Drilled shafts	3.2 Pier type	Beam-column frame
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? None			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? None			
3.5 Temporary structure type: Steel			
3.6 Was there significant deformations observed on the temporary works during sliding operations? Not sure			
4. Superstructure over pier			
4.1 Girder type	Pre-stressed bulb-tee girder	4.2 Diaphragm type	Concrete
4.3 How was the performance of the diaphragm over piers? Not sure			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern? Yes, I-405 over NE 8th Street			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Not sure			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. Not sure			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. Not sure			

<table>
<tr><th colspan="4">1. Basic information</th></tr>
<tr><td>1.1 Bridge ID</td><td>Elk Creek Bridge No. 3</td><td>1.2 State</td><td>OR</td></tr>
<tr><td>1.3 Project year</td><td>2008</td><td>1.4 Total number of spans</td><td>3 spans</td></tr>
<tr><td>1.5 Span length (ft)</td><td>56.5'-207.5'-56.5'</td><td>1.6 Total length (ft)</td><td>320.5'</td></tr>
<tr><td>1.7 Total width (ft)</td><td>38.2'</td><td></td><td></td></tr>
<tr><th colspan="4">2. Sliding system</th></tr>
<tr><td colspan="3">2.1 What is the maximum number of the spans in each slide?</td><td>2</td></tr>
<tr><td colspan="4">2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it?
Hydraulic jack</td></tr>
<tr><td colspan="4">2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling?
Not sure</td></tr>
<tr><td colspan="4">2.4 Sliding system (Over pier):Stainless steel shoes on Teflon pads</td></tr>
<tr><td colspan="4">2.5 What was the friction level?
Not sure</td></tr>
<tr><td colspan="4">2.6 Type of steering control system:
Not sure</td></tr>
<tr><td colspan="4">2.7 What was dynamic impact factors associated with multi-span sliding?
Not sure</td></tr>
<tr><th colspan="4">3. Substructure near pier</th></tr>
<tr><td>3.1 Foundation type</td><td>Drilled shaft</td><td>3.2 Pier type</td><td>Beam-column</td></tr>
<tr><td colspan="4">3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance?
Not sure</td></tr>
<tr><td colspan="4">3.4 What method was used to overcome the uplift force during sliding? How was the performance?
Not sure</td></tr>
<tr><td colspan="4">3.5 Temporary structure type:</td></tr>
<tr><td colspan="4">3.6 Was there significant deformations observed on the temporary works during sliding operations?
Not sure</td></tr>
<tr><th colspan="4">4. Superstructure over pier</th></tr>
<tr><td>4.1 Girder type</td><td>Box beam girder</td><td>4.2 Diaphragm type</td><td>Concrete</td></tr>
<tr><td colspan="4">4.3 How was the performance of the diaphragm over piers? Not sure</td></tr>
<tr><td colspan="4">4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?
None</td></tr>
<tr><th colspan="4">5. Investigation</th></tr>
<tr><td colspan="4">5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result?
Not sure</td></tr>
<tr><td colspan="4">5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process.
Not sure</td></tr>
<tr><td colspan="4">5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process.
Not sure</td></tr>
</table>

1. Basic information			
1.1 Bridge ID	Ben Sawyer	1.2 State	SC
1.3 Project year	2011	1.4 Total number of spans	13
1.5 Span length (ft)	70' & 86' (Approach Spans), 247' (Swing Span)		
1.6 Total length (ft)	1,154'-2"	1.7 Total width (ft)	36'
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			6
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it?			
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Pulling			
2.4 Sliding system (Over pier): Roller			
2.5 What was the friction level? Not sure			
2.6 Type of steering control system: Not sure			
2.7 What was dynamic impact factors associated with multi-span sliding? Not measured			
3. Substructure near pier			
3.1 Foundation type	End Bents – timber piles, Interior Bents (approach spans) – pile footings (probably timber piles), Pivot Pier (swing span) – pile footings (probably timber piles) – Reused	3.2 Pier type	End Bents – concrete bent caps supported by timber piles, Interior Bents (approach spans) – multi-column concrete bents on pile footings (probably timber piles), Pivot Pier (swing span) – concrete on pile footings (probably timber) – Reused
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Not sure			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? Not sure			
3.5 Temporary structure type: steel pipe pile + inline steel structural steel girders			
3.6 Was there significant deformations observed on the temporary works during sliding operations? None that was observed			
4. Superstructure over pier			
4.1 Girder type	Approach Spans – structural steel plate girders, Swing Span – structural steel truss	4.2 Diaphragm type	Approach Spans – structural steel W beams and plate girders, Swing Span – N/A
4.3 How was the performance of the diaphragm over piers? Good			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? The rollers were supported on steel beams where PCL welded angle iron onto one edge of the beams to control the direction of the rollers; lateral flexural stresses are not a concern			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. A system of dial gauges was used to measure any lateral movement in the existing pile caps			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. None			

1. Basic information			
1.1 Bridge ID	I-44 over Gasconade River	1.2 State	MO
1.3 Project year	2011	1.4 Total number of spans	6
1.5 Span length (ft)	60'+120'+150'+150'+120'+70'	1.6 Total length (ft)	668.5'
1.7 Total width (ft)	36.7'		

2. Sliding system	
2.1 What is the maximum number of the spans in each slide?	6
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Seven locations; at each diaphragm	
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Not sure	
2.4 Sliding system (Over pier): Not sure	
2.5 What was the friction level? Not sure	
2.6 Type of steering control system: Not sure	
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure	

3. Substructure near pier			
3.1 Foundation type	Spread footing	3.2 Pier type	Beam column (reused)
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Did check for the overturning during the design			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? No, performance well			
3.5 Temporary structure type: Inline concrete structure on drilled shaft foundation			
3.6 Was there significant deformations observed on the temporary works during sliding operations? None			

4. Superstructure over pier			
4.1 Girder type	Steel plate girders	4.2 Diaphragm type	Steel
4.3 How was the performance of the diaphragm over piers? No problem			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?			

5. Investigation
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Survey; using laser equipment measure the sliding distance on over each pier
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. None
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. None

1. Basic information			
1.1 Bridge ID	Sellwood Bridge	1.2 State	OR
1.3 Project year	2013	1.4 Total number of spans	
1.5 Span length (ft)		1.6 Total length (ft)	1,100'
1.7 Total width (ft)			
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Not sure			
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Not sure			
2.4 Sliding system (Over pier): Not sure			
2.5 What was the friction level? Not sure			
2.6 Type of steering control system: Not sure			
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure			
3. Substructure near pier			
3.1 Foundation type		3.2 Pier type	Wall pier
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Not sure			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? Not sure			
3.5 Temporary structure type: Steel			
3.6 Was there significant deformations observed on the temporary works during sliding operations? Not sure			
4. Superstructure over pier			
4.1 Girder type	Steel truss bridge	4.2 Diaphragm type	Truss
4.3 How was the performance of the diaphragm over piers? Not sure			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern? None			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Not sure			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. Not sure			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. Not sure			

1. Basic information			
1.1 Bridge ID	I-84 (EB&WB)	1.2 State	NY
1.3 Project year	2013	1.4 Total number of spans	1span +2approach slab
1.5 Span length (ft)	33'+80'+33'	1.6 Total length (ft)	146'
1.7 Total width (ft)	60'		
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			1span +2approach slab
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Two interim diaphragms. The equipment’s hydraulic capacity was sufficient and the monitoring of movement and coordination among the monitors to ensure movement at the same rate would be less complicated and would require fewer resources.			
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Hydraulic jacket, push			
2.4 Sliding system (Over pier):Stainless steel shoes on unguided Teflon pad			
2.5 What was the friction level? Assume 10% of the weight plus a little extra to overcome the static friction. No lab or field test.			
2.6 Type of steering control system: Displacement control/Pressure control/Other__________			
2.7 What was dynamic impact factors associated with multi-span sliding? Not measured			
3. Substructure near pier			
3.1 Foundation type	Drilled shaft	3.2 Pier type	Straddle bent abutment
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Not a concern. Bridge substructure is very wide and good to resist the overturning.			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? No effect was made on this			
3.5 Temporary structure type: Inline steel			
3.6 Was there significant deformations observed on the temporary works during sliding operations? No significant deformations on the temporary structure. Before the sliding, there was some concern on the different settlement between the temporary and permeant substructures. Trail slide was conducted on field to see the lateral movement of the temporary structure during each push.			
4. Superstructure over pier			
4.1 Girder type	Double Tee	4.2 Diaphragm type	Concrete
4.3 How was the performance of the diaphragm over piers? Good. Very rigid. Not an issue.			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern? No concern. There are two more bridges in NY having steel girders and constructed using SIBC.			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Pre-mark the sliding distance for each push. Check and communicate the progress after each push. Bridge superstructure made of concrete girder is very stiff. The lateral flexural is not a concern.			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. None			

5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process.
None

1. Basic information			
1.1 Bridge ID	Larpenteur Avenue Bridge	1.2 State	MN
1.3 Project year	2014	1.4 Total number of spans	2
1.5 Span length (ft)	91.2'-91.2'	1.6 Total length (ft)	185.5'
1.7 Total width (ft)	61		
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			2
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Four in total. Two jacks at the pier, one jack at each abutment.			
2.4 Sliding system (Over pier): Stainless steel shoes +Teflon pad			
2.5 What was the friction level? Not sure			
2.6 Type of steering control system: Displacement was measured and pressure was monitored			
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure			
3. Substructure near pier			
3.1 Foundation type	Spread footings	3.2 Pier type	Beam-column
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Not considered during design. No issues on the substructure performance.			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? None			
3.5 Temporary structure type: Inline steel			
3.6 Was there significant deformations observed on the temporary works during sliding operations? None			
4. Superstructure over pier			
4.1 Girder type	Prestressed concrete beams	4.2 Diaphragm type	Concrete
4.3 How was the performance of the diaphragm over piers? No significant issue			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diaphragm designed? If no, what is the concern? Yes. Steel diaphragm.			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? No. The lateral sliding was tracked with tape measure, visually inspection etc. But there is no issue on lateral flexural stresses.			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. None			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. None			

1. Basic information			
1.1 Bridge ID	M-50 over I-96	1.2 State	MI
1.3 Project year	2014	1.4 Total number of spans	2 spans
1.5 Span length (ft)	99'-99'	1.6 Total length (ft)	198'
1.7 Total width (ft)	71.25'		
2. Sliding system			
2.1 What is the maximum number of the spans in each slide?			2
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? The plan was to push the superstructure at three diaphragms. During the sliding, the hydraulic jack over the pier failed. The sliding was accomplished with the two jacks at the abutment.			
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Hydralic jack system, pushing. The performance is good.			
2.4 Sliding system (Over pier):Stainless steel shoes on guided Teflon pad			
2.5 What was the friction level? The friction level was decided based on the bridge state design manual https://mdotcf.state.mi.us/public/design/englishbridgemanual/			
2.6 Type of steering control system: Displacement control was used and the pressure was monitored and controlled.			
2.7 What was dynamic impact factors associated with multi-span sliding?			
3. Substructure near pier			
3.1 Foundation type	Beam-column frame	3.2 Pier type	Spread footing
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? Not considered			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? Number of pile was checked to ensure that they could resist the uplift force, check the friction level.			
3.5 Temporary structure type: Steel Inline			
3.6 Was there significant deformations observed on the temporary works during sliding operations? No significant deformation. Before the sliding, the different settlement between the temporary structure and permanent structure was checked.			
4. Superstructure over pier			
4.1 Girder type	Box beam girder	4.2 Diaphragm type	Concrete
4.3 How was the performance of the diaphragm over piers? Good			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern? Yes, another single-span bridge with steel plate girder was constructed using SIBC method			
5. Investigation			
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Surveying. Geometry control plan.			
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. Yes. Geometry control plan.			
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. Yes, contractor did a FEA to look at the sliding effect			

1. Basic information			
1.1 Bridge ID	Poplar Street Bridge	1.2 State	MO
1.3 Project year	2018	1.4 Total number of spans	5
1.5 Span length (ft)	300'+500'+600'+500'+265'	1.6 Total length (ft)	2,165'
1.7 Total width (ft)	112		

2. Sliding system	
2.1 What is the maximum number of the spans in each slide?	5
2.2 Where the lateral forces were applied (how many locations were pushed)? And what were the efficiency, drawbacks, and advantages of it? Six location; at each diaphragm	
2.3 What are the efficiency, drawbacks, and advantages of pushing or pulling? Not sure	
2.4 Sliding system (Over pier): Not sure	
2.5 What was the friction level? Not sure	
2.6 Type of steering control system: Not sure	
2.7 What was dynamic impact factors associated with multi-span sliding? Not sure	

3. Substructure near pier			
3.1 Foundation type	Driven pile	3.2 Pier type	Beam column (reused)
3.3 What was the design or detailing consideration to prevent the pier overturning during the SIBC of the multi-span bridges? What was the actual performance? None			
3.4 What method was used to overcome the uplift force during sliding? How was the performance? None			
3.5 Temporary structure type: No temporary structure was used			
3.6 Was there significant deformations observed on the temporary works during sliding operations?			

4. Superstructure over pier			
4.1 Girder type	Steel box girder	4.2 Diaphragm type	Steel
4.3 How was the performance of the diaphragm over piers? Very good. The steel deck create significant stiffness. The whole superstructure is very stiff.			
4.4 Have you used SIBC on the rolled steel girder bridge? If yes, what was the pier diagram designed? If no, what is the concern?			

5. Investigation
5.1 Was there any tracking on the lateral slide progress to minimize lateral flexural stresses at continuous girders at piers? If yes, how was it tracked and what is the result? Surveying
5.2 Was there any monitoring work conducted on the substructure (including pier, pile etc.)? If yes, what was the interest? Please briefly talk about the monitoring process. None
5.3 Was there any analytical analysis (for example, finite element analysis etc.) conducted to evaluate structure behavior on the substructures (including pier, abutment, pile etc.)? If yes, what was the interest? Please briefly talk about the analytical analysis process. FEA on superstructure and substructure for seismic resistance and barge collide

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