Sliding and Rolling Bridge *Solutions*–Part 1

by Craig A. Shutt

As owners look to save costs and erect bridges faster with less interference to the traveling public, the concepts of sliding and rolling bridges transversely into place after constructing them nearby are becoming more popular. These techniques offer benefits, but they require unique considerations that can make the difference between success and failure. Both design and construction teams must understand these movement considerations.

Sliding or rolling bridges into place has become accepted by contractors due to the tighter time restrictions owners are placing on projects and their awareness of user costs for tying up either roadway access or waterways. These approaches also can help minimize environmental impact during and after construction.

In some cases, owners require this delivery method in their contract documents, necessitating designers and contractors to become familiar with the techniques as soon as they can. In these cases, clients often want to avoid employing cranes on small sites, which create economic drawbacks. On the plus side, owners don't typically provide detailed requirements for how the bridge should be moved into place. When they do, they often allow contractors to propose alternatives, ensuring the most efficient approach can be employed.

There are three typical options when considering how to move bridges into place:

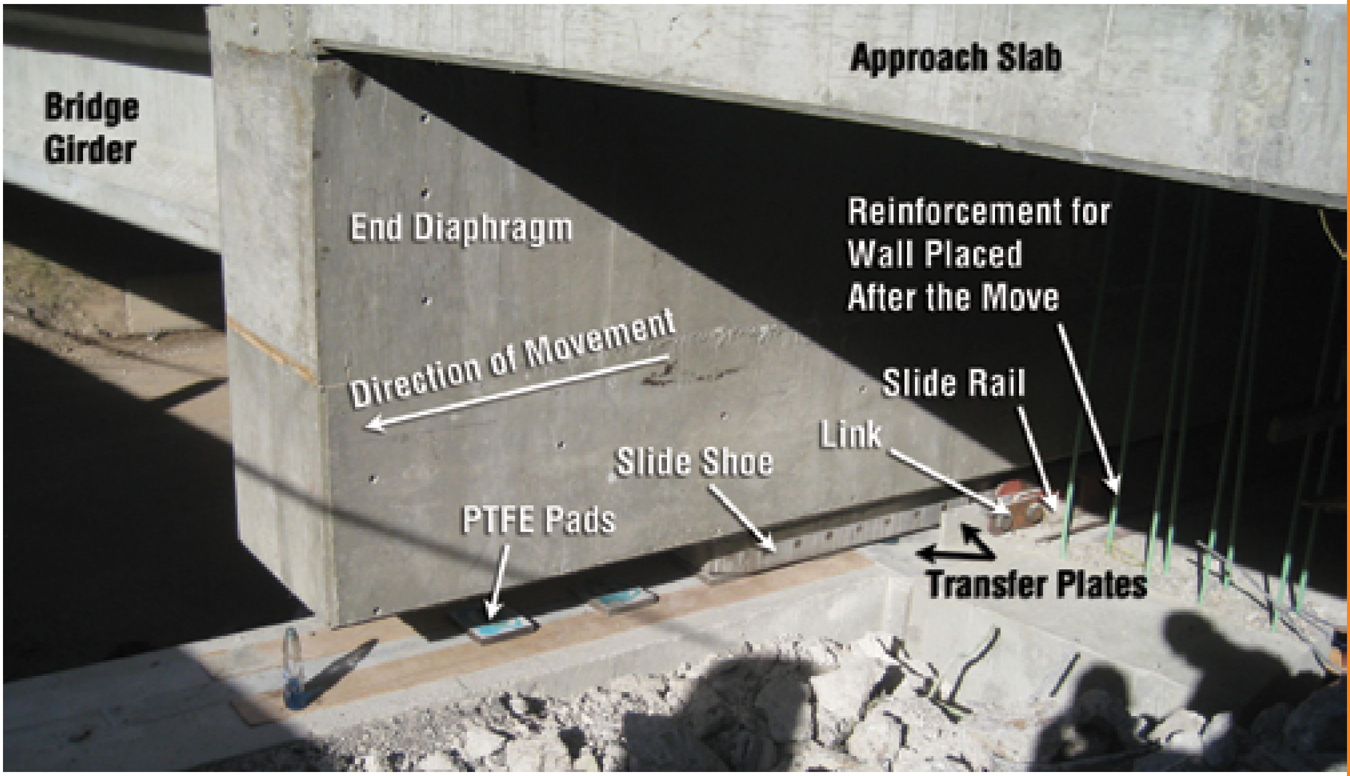
- Pushing with hydraulic jacks on rollers or pads
- Pulling with hydraulic jacks or cables on rollers or pads
- Moving with self-propelled modular transporters (SPMTs)

This article and the next in the *ASPIRE*™ accelerated bridge construction (ABC) series will deal with design issues of the first two types, sliding or rolling the components into place. These will be followed by a look at necessary activities in the field during construction. The use of SPMTs will be addressed in a subsequent article.

Define Duties

Because few companies have deep experience with these projects yet, it is critical for engineers and contractors to define each member's duties, requirements and who will be responsible for all the means and methods. Typically, the means and methods will derive from the contractor's preference, based on the method with which the contractor is most comfortable.

In creating a construction plan, the design team should develop an ABC strategy with requirements for as-builts or contingency



As used on the I-80 bridges over Echo Dam Road in Echo, Utah, the slide shoes on the bottom of the abutment wall glide across polytetrafluorethylene (PTFE) pads onto the permanent abutment. Photo: Michael Baker Jr. Inc.

Jacking pockets in concrete end diaphragms are shown with the jacks. Photos: Horrock Engineers.

plans and sequencing plans for closure periods for the road. Some departments of transportation have developed ABC specifications to cover additional requirements of the contractor or design-builder when utilizing ABC moving techniques. In some cases, these special provisions can become very specific. Too restrictive of an ABC specification can limit innovation during bidding.

Concrete Solutions Available

Concrete components provide many workable solutions for ABC. Some owners or contractors discourage the use of concrete when sliding components due to the added weight. The additional weight of concrete components is normally not a problem on bridge slides. The jacks typically have more capacity than needed.

The increase in weight does impact the temporary-support structure. But in general, concrete components offer no more difficulties than other materials in construction and provide benefits in speed of delivery, better durability over the bridge's service life, and less maintenance.

Lightweight concrete can be used to mitigate the dead-load considerations, although it is not essential. Other options can optimize handling needs, including prestressing, post-tensioning, and the use of cast-in-place concrete joints.

Superstructure Design

Superstructure design of ABC bridges is generally the same as that used for conventional construction. The major difference occurs at the abutment. In the conventional bridge design, the girder loads pass directly into the abutment. When the bridge is rolled or slid, either the end diaphragms of the bridge have to be designed to support the bridge on the sliding shoes or rollers or the girders must be designed to accommodate both the sliding or rolling bearings and the permanent bearings.

Throughout the process of designing and detailing the structure, construction sequencing should remain a priority. For instance, the lower diaphragms can be unstable during girder erection in its temporary condition because the lower diaphragm is only supported vertically on the temporary supports. This produces a partial hinge. Bracing the diaphragms until all girders are set and the upper diaphragm concrete is placed eliminates this concern.

Sliding Forces

The designer should consider all the elements of the pushing or pulling system—ram, slide rail, and push blocks—when planning the process of moving the bridge into place. The pushing or pulling ram will most likely require a steel-to-steel connection, as it is the sole link allowing the structure to move. Details should allow the steel pushing or pulling block to be easily bolted on to the superstructure and then removed after the slide. Bridge skew can play a large part in the design of the pushing or pulling block.

The required force to move the bridge is a function of the weight of the superstructures and the coefficient of friction between the skid shoes and the polytetrafluorethylene (PTFE) pads over which the skid shoes slide or the rolling resistance of roller bearings. Coefficients of friction for PTFE bearings are given in the *AASHTO LRFD Bridge Design Specifications*, Chapter 14. Data are also available from product manufacturers.

Based on recent project experience, static coefficients in the range of 0.09 to 0.12 and dynamic coefficients in the range of 0.05 to 0.06 are reasonable values to consider for lubricated PTFE bearings sliding against polished stainless steel skid shoes.

The pushing or pulling mechanisms should have a capacity in excess of the calculated pushing or pulling force. Some designers recommend that the entire moving system be designed for the full capacity of the hydraulic system so the connections cannot be over-loaded by the jacking system, in case the system binds up and is not immediately detected by the operator.

Coordination early and often with the bridge-move subcontractor is highly recommended.

Push block between the hydraulic jack and the abutment must handle an axial load plus a horizontal shear without damaging the end of the diaphragm. Photo: Horrock Engineers.

Approach Slabs

In sliding- or rolling-bridge applications, moving the approach slabs along with the main span can be effective. This resolves key challenges affecting rideability of the roadway after construction and reduces closure times. Falsework and shoring can be designed to support the approach slabs during construction.

There can be dead-load deflection when casting the approach slabs on shored construction. This deflection can be handled by recognizing its impact, and the benefits in speed and ultimate road smoothness are worth the effort. Shored construction will also result in compression in the top of the slab when the shoring is removed, possibly improving its cracking resistance.

Expansion joints can be set in the approach slabs and locked into place until after the move. This allows the expansion to take place, after which the surface can be paved, if required. One team reported that this method saved critical time during the construction-launch period.

Normally, the approach slab-to-bridge connection is designed to accommodate rotation. The approach slab will need to be lifted concurrently with the bridge if the rotation on the joint during the jacking and moving process exceeds the beam limit. If the expansion joint is at the end of the approach slab, then precast concrete sleeper slabs may be needed.

Substructure Considerations

A key temporary-foundation element involves designing piles or spread footings to support the bridge in its temporary position. Pile locations can be out of line by more than 6 in., so it is critical that some tolerance is delineated for them to be welded to the slide rail-support system (which often is separate from the slide rails themselves) that will support the bridge during construction and during the move.

One easy way to accomplish this is to weld an oversized plate onto the top of the pile. The plate can then support the slide-rail supports. In most cases, the slide rails require tight vertical tolerances. Allowing for adjustments in the slide-rail elevations to ensure a smooth and level sliding surface provides the best solution.

Likewise, consideration should be given to the possibility that abutments will deflect when the bridge weight is moved into place. This typically isn't noticed in a more traditional method of construction, using cranes or launchers, because that weight is added incrementally and any deflections can be accommodated in the haunch or deck thickness. But when sliding the bridge into place, all of that significant weight is placed on the abutments at about the same time, so deflections of the permanent support from the partial and complete loading process need to be considered.

These adaptations need to be made at the design stage, as contractors must build the components to the plan dimensions to ensure the final bridge elevations match the required final profile. In some cases, when one abutment is out of line longitudinally, adjustments by the use of guide rails can be made to counteract anticipated and unanticipated movements in unguided systems.

Temporary strap tying the approach slab to the bridge deck slab. Photo: Horrock Engineers.

Some tolerance is needed to allow for minor differences in the extensions of each jack. This difference in movement will rotate the structure in plan view. Bridges have been successfully slid into place with less than a 2-in. tolerance allowance.

Construction of new substructure elements around existing elements requires consideration of stability during construction. Temporary bracing of existing substructures or top-down retaining walls (soil nails or mechanically stabilized earth) may be required to ensure stability of the system during construction. Specifications defining construction submittals or design plans for shoring of the existing bridge should be included on the plan set.

Soil nails or other bracing often are required, and their construction can make or break the schedule. Stabilizing this soil at the abutments is critical, as delays can result in all other scheduled activities being delayed as well. Significant and detailed analysis needs to be performed to ensure the temporary structures and existing spread footings, if used, will not settle once the dead loads are transferred. A

This is the first in a series of articles examining different approaches to accelerated bridge construction. This report was produced from interviews with Hugh Boyle, chief engineer at H. Boyle Engineering; Mike Dobry, principal structures engineer, Larry Reasch, vice president and manager of the structures department, and Derek Stonebraker, structures engineer, at Horrock Engineers; R. Craig Finley Jr., founder and managing partner at Finley Engineering Group; and Steve Hague, chief bridge engineer at Burns & McDonnell.

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Sliding and Rolling Bridge *Solutions*–Part 2

by Craig A. Shutt

Sliding and rolling bridges into place after assembling them nearby has gained adherents as efficient construction techniques for saving time and costs and minimizing traffic disruption. Owners, designers, and contractors are quickly learning as much as possible about these new concepts so they are ready to discuss options when opportunities arise. This series of articles looks at some of the key considerations when using these approaches to bridge construction.

Part 1 of this series considered key design considerations, including allocating duties among the construction team, superstructure and substructure concerns, and evaluating sliding forces.

This article considers falsework and related design issues. The next article will review necessary field activities during construction. The use of self-propelled modular transporters will be addressed in a subsequent article.

Falsework Design

The design for temporary falsework depends on the application, but in any form it represents a key element to ensuring the structure is safely fabricated offline and out of the critical path, allowing for accelerated bridge construction (ABC). Building falsework next to the existing bridge location allows assembly of the new components to be completed while other key elements of the construction also are underway (such as piers and abutments).

Extensive falsework and shoring requirements must be considered when sliding or rolling bridge superstructure systems into place. The falsework's constructability is critical to ensure the falsework provides the various functions required to build the bridge components and then move them into place. This means every aspect must be detailed in the shop drawings to ensure the falsework is built to perform as the specifications require.

The temporary shoring and permanent abutment must be checked for large temporary lateral forces during launching. However, if a problem arises (such as excessive settlement) during the transfer of the bridge from the falsework to its permanent support, the shoring system has to be able to accommodate and possibly support greater lateral construction loads.

For most projects, settlement of the falsework as it carries the load (during launching) of the bridge doesn't become an issue. The falsework will deflect slightly but not enough to be a concern. Even so, it is preferable to consider and evaluate this possibility to ensure the falsework is sufficiently rigid.

If the falsework does deflect too much, it will be necessary to jack up the bridge once it reaches its final landing point or transfer point if using the permanent structure to support the slide rails. A counter concern is that there can be difficulties if the falsework is too high as well.

On the West Mesquite Interchange at I-15 in Mesquite, Nev., hydraulic jacks were used to push the bridge into place. All photos: Jackie Borman, HDR.

In some cases with push/pull jacks, contractors have investigated the use of the falsework as an anchor point. This generally has not been done, as the falsework needs to be kept as light (and therefore economical) as possible. It is better to push against or pull toward something more rigid (that will ultimately act as a component of the permanent system), such as the abutments.

In some cases where space is limited, these lateral bridge-supporting devices can be built on the other side of the existing bridge from the new bridge, allowing that old bridge superstructure to be pulled out of the way and the new bridge to be moved into place behind it.

Sliding Forces

With a static coefficient of friction of 0.12, the required force to slide a 1.3-million-lb concrete superstructure is 156 kips (1,300,000 lb × 0.12/1000). This can easily be achieved with two 100-kip jacks, which are readily available.

Although a concrete bridge typically weighs about 50% more than a steel bridge, and thus a higher force is needed to move the bridge, the associated equipment and costs are not directly proportional—that is, the cost to rent the hoses, pumps, gauges, and a set of two 100-kip jacks is comparable to renting a complete system with two 60-kip jacks.

Transfer to Permanent Supports

Moving the structure from the sliding shoes to the permanent bearings is a critical step in construction that must be considered very carefully. In many cases, the bridge will be transferred from the sliding rails onto jacks and then lowered onto new permanent bearings. In some cases, the bearings under the beams can remain in place during the transfer. In any case, the bearings and guide rails should be horizontal to avoid moving the bridge uphill or downhill. Depending on

Teflon pads on rails assisted in sliding the approach slab and bridge into place on the West Mesquite Interchange at I-15 in Mesquite, Nev.

how the beams are oriented, there may need to be either grout pads or shim plates between the bearings and the beams.

It's critical to understand how the bridge will react to the shift from its temporary position to its permanent one to be certain that the shift won't create undesirable stresses. The design must account for these stresses in its temporary position as well as in its permanent location. These details become extremely important during the move, whereas they are not as critical in other types of construction.

For instance, a skew in a bridge results in the diaphragm face not being perpendicular to the abutment. This requires a transfer plate or push block between the hydraulic jack and the abutment that can handle an axial load plus a horizontal shear without damaging the end of the diaphragm. Confinement reinforcement in the diaphragm at the connection point may be needed.

Design Considerations

Design elements need to be coordinated at every stage with the construction means and methods. The engineer coordinates the move with the heavy-mover subcontractor early in the design process. The engineer must understand what equipment the contractor will be using and how it will support and load the bridge during the move and in its permanent location. Different design approaches are required to make sure that these things happen and to ensure factors such as bending over the supports and deck cracking are considered. Design details, that in other forms of construction are insignificant or can be dealt with in the field, become critical when moving a bridge into place.

Wind-speed limitations, for instance, need to be worked out with the contractor in advance so a maximum is set beyond which the construction will not go forward. This typically is set at about 15 mph, but it will be up to the contractor to determine what can be tolerated by the equipment and comply with this limit.

At every step of the process, engineers must account for the numerous stresses and how they vary during the moving process. Likewise, the contractor needs to be diligent about the quality of construction and building the bridge exactly to the plans. Small field changes can alter the load path of the entire structure due to the complexities of the movements being handled.

The contractor's specialty engineer needs to be closely focused on any field design changes that occur to ensure they are accounted for in the loading in each phase. Each part, starting with the skid shoes or roller troughs, has to be aligned with absolute precision to ensure the bridge movement can proceed easily once it starts and that the system does not bind up.

For that reason, it is wise to build redundancy into the movement-system hardware wherever possible. Adding lateral connections will only result in a minor increase in costs, but it can resolve problems that may arise. It's critical to consider every risk and worst-case scenario to decide how it will be handled. The value of extra anchor bolts in these push/pull systems versus the problems with a failed connection provides low-cost insurance, even if it ultimately proves to be unnecessary.

The key to a successful project using slide-in or roll-in construction is to think through every step: designing falsework to handle movement and transfer loads; stresses during moving, lifting, and setting the beams into their permanent place; and the like. Every factor and every possible concern must be considered against what impact it will have on every other portion of the bridge. To ensure success, the engineer, contractor, and the heavy lifting sub-contractor must work through every contingency and create a plan that will handle each possibility that could possibly arise—and be imaginative in considering what those options could be.

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Overall view of the approach slab and end diaphragm of the north half of the West Mesquite Interchange at I-15 sliding into place by a hydraulic jacking system.

Sliding and Rolling Bridge *Solutions*–Part 3

by Craig A. Shutt

Construction of falsework for the new bridge begins on the right side. All photos: Hilman Rollers.

Construction of widened substructure begins on the left side.

The deck is ready for casting concrete.

The old bridge has been removed and the new bridge is ready to be moved into place.

The new bridge is in its final location.

Sliding and rolling bridges into place offers key benefits to owners, designers, and contractors. As a result, more bridges are being designed and built using these techniques. This series of articles looks at some of the key considerations when using these approaches to construct bridges.

The first two parts of this series examined key design considerations that impact construction. This part addresses construction considerations.

Pads

Pads are a simple, low-cost solution. They offer significant directional flexibility, as the direction of movement is not tied to the orientation of the pads. Pads also allow the use of an unguided system that will not bind if ends of the bridge move at different rates.

Normally, the superstructure is lifted prior to the slide, to allow the skid shoes and bearings to be cleaned and to apply a non-petroleum-based synthetic grease onto the sliding surface. Continuous lubrication of the pads is critical during the slide, especially to overcome the initial inertia and achieve the breakaway force.

Fortunately, many types of inexpensive lubrication can be used. A variety of biodegradable lubricants are available that won't damage the pads. A popular option is dish soap, readily available from any mass-merchant store, but it dries quickly if left for any time. One contractor uses bananas as lubricant. Whatever is readily available, inexpensive, and has been found to be effective can be put into service for this need.

Skid shoes should be braced during construction to maintain a level slide surface. Normally, the sliding surface of the shoe consists of polished stainless steel. There are many ways to construct skid shoes. One method uses concrete-filled steel shapes using steel as thin as ¼ in. Other methods use steel box or I-sections with the base plate at least ¾ in. thick. Thinner shoes can deflect or warp during construction, creating an uneven sliding surface. Beveled ends should be used to ease sliding over the pads and limit friction.

Rollers

Rollers are more costly than pads but have a longer service life. They are often used on bridge projects with larger load requirements. When properly sized, the slide resistance is more predictable and requires less force to start and stop the bridge. Undersized rollers can dimple the slide surface, which can significantly increase the starting force.

Rollers are almost always guided with troughs or channels that align the rollers during the move. Roller-guide surfaces can be flush or approximately 2 to 3 in. wider than the rollers to allow room as the jacks push or pull the bridge. These channels must be kept clean and clear at all times to ensure no obstructions for the rollers.

Rollers were used between the end diaphragms and the temporary substructure on the I-205 Redland Road overpass in Oregon.

Contractors using rollers must fully understand the tolerance issues, know the requirements to achieve the breakaway force, and monitor when to reduce the force once the bridge begins moving. These calculations must be precise, as any deviation can bind up the system and require time-consuming adjustment.

Push-Pull Options

The decision to use jacks to pull or push the bridge will depend on a variety of specific factors, including terrain, bridge design, and contractor preference. Typically, the deciding factor is the contractor's preference given the specifics of the bridge under construction.

When pushing a bridge, temporary abutments are used with self-setting jacks. When pulling the bridge, the mechanism relies on cables attached to an electric drum, strand, or threaded bars. Anchor points are needed to secure the jacks. Often, the jacks are anchored to the existing bridge beyond the replacement bridge being pulled into place.

Tension rods are anchored at the abutment to create a reaction point. Note the bracket to accommodate the skew of the bridge.

This before and after view shows how the abutment was changed once the bridge was moved into place. Note the channel guide rail and tension rods.

In either format, it is critical that the movement is monitored to ensure the jacks move at the same rate. Uneven movement often occurs due to differences in friction regardless of how careful the system is designed. Early correction of uneven movement minimizes the potential for binding or final misalignment.

Monitoring is especially important on bridges moved without guides. Without guides, the structure will move back and forth as rams will most likely be hydraulically connected and not using a displacement-based control. Achieving a final alignment within the specified tolerance can be time consuming, especially when inadequate monitoring allows significant racking or rotation to occur.

Jacks

When pushing the bridge, restroke jacks are used, with no stroke length greater than 30 in. Longer strokes take too long and can create bending in the jack piston. A push range of 6 to 18 in. is recommended.

Typically, the jack features a home rail with pins, with the piston pushing to advance the bridge, after which the pins are advanced (or a second set of pins are inserted) at about 6-in. increments. Double-acting rams can retract quickly, moving the bridge at a faster rate. Pressure in the system may not always be proportional to the jacking force because of friction in the jack.

A trial-and-error approach, along with the use of a measuring stick along the rails, will best determine how far the bridge can be moved at once. If one side moves farther, however, adjustments must be made quickly. Workers should be assigned to each corner to watch the longitudinal and lateral movement carefully.

A simple measuring system is needed to monitor bridge movement at both abutments.

Terrain

It is best to move the bridge on a horizontal surface, irrespective of any slope in the terrain. A complete evaluation of soil conditions is critical to ensure adequate support during the move, especially under the launching rails.

Typically, it is more advantageous to move the bridge uphill if a level surface cannot be provided, as it makes it easier to control movement. Moving downhill requires a launch mechanism that includes heavy-duty brakes or a restraining system to restrain movement when gravity tries to take over.

In all cases, a test run will help assess any concerns. This should include actually moving the bridge, even if only by a few inches.

Key Stages

The initial lifting of the structure to place the slide system can be the controlling load case for the shoring system. Next, the initial movement creates the largest horizontal force demand and the maximum transverse force in the shoring system. During the slide, transitioning from the temporary support to the final support can cause differential deflections between the supports. This stage maximizes the vertical-load demand on the connection element. The final stage places the bridge on the permanent bearings.

Typically, permanent bearings are thicker than pads and shorter than rollers. After the bridge is aligned in its final position, it is jacked up, the slide system is removed, and permanent bearings are placed. Shim plates can be used to correct any elevation discrepancies in the bearing surface on the permanent abutment or variation in the bottom of the substructure elevations.

Other Considerations

Integral diaphragms and shoes provide a robust section and minimize differential deflection between girder lines. Normal cross-frames provide a more flexible system and can reduce the impacts of differential deflection in the slide supports.

Use of two slide supports increases the load per support but minimizes the variation in load due to an uneven slide surface. Three or more slide supports reduce the average load per support, but it also can concentrate the load onto a single support if the system is stiff and the slide surface has a high point.

Often, pads are reused in a slide as the bridge transitions over them. At the final move into the bridge's permanent position, new pads are placed and left in place. They are locked in with shear keys after the bridge is positioned. Detailing gaps between the skid shoes can allow temporary and final bearings to be switched during the final push.

Deck cracking due to lateral moves is rare. The deck is vulnerable during the initial or final jacking, but the loads are similar to those encountered in a normal bearing-replacement project. The deck can also be stressed when a high point is encountered by the rollers or slide shoes during the move. Bridges using a flexible cross-bracing system are more vulnerable.

No matter how well thought out the process and how high the quality, these projects should always have contingency plans. These plans typically include backup power for the rams, backup rams themselves, additional bearings, redundant load paths, and other accessory parts.

As contractors and engineers become more experienced with this type of construction, some of these requirements will become second nature. That will not reduce their importance. A strategy must be developed to ensure the owner receives an acceptable as-built bridge. The contractor's team must be diligent about every aspect of the project to ensure its success.

This is the third in a series of articles examining approaches to accelerated bridge construction as it applies to slide-in bridge construction. This report was produced from interviews with Hugh Boyle, chief engineer at H. Boyle Engineering; Mike Dobry, principal structures engineer, Larry Reasch, vice president and manager of the structures department, and Derek Stonebraker, structures engineer, at Horrock Engineers; R. Craig Finley Jr., founder and managing partner at Finley Engineering Group; and Steve Hague, formerly chief bridge engineer at Burns & McDonnell.

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