Journal of Highway and Transportation Research and Development

Home page: www.sciopen.com/journal/2095-6215

Sliding deck-extension abutments: A new concept for jointless bridges

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Abstract: Integral and semi-integral abutment bridges (SIAB) offer significant advantages over conventional bridges with expansion joints, including improved durability and reduced long-term maintenance requirements. However, conventional SIAB systems continue to rely on physical bearings, which are susceptible to potential maintenance issues and replacement. A novel deck-extension sliding semi-integral abutment bridge system is then proposed in which conventional bearings are replaced with low-friction sliding interfaces. The proposed system incorporates sliding surfaces between the superstructure and the top of the abutment, as well as between the underside of the deck extension and the top of the abutment backwall. By accommodating thermal movements through sliding rather than bearing deformation, the proposed system would also reduce/eliminate the passive earth pressures developed behind the abutment during bridge thermal expansion. An experimental program evaluated the cyclic frictional behavior of conventional polyethylene and ultra-high-molecular-weight polyethylene interfaces as two candidate interfacial materials. Results are promising for the proposed bearing-free (sliding) semi-integral bridge abutments.

Keywords: Jointless bridges; sliding semi-integral abutment; deck-extension; thermal movement; soil pressure

1 Introduction

Bridge expansion joints accommodate movements caused by temperature variations and other deformation processes. However, throughout the course of a bridge's service life, these elements could introduce maintenance and durability issues. Expansion joint failures can significantly increase bridge maintenance costs over the service life of the bridge. Failing expansion joints provide direct routes for water and deicing chemical leakage, which over time contributes to the deterioration of the substructure and superstructure elements [1]. Removing expansion joints can thus lessen the need for maintenance and rehabilitation, and traffic disruption [1].

Jointless bridges are an alternative to conventional bridges with expansion joints. The way movements related to temperature, creep, shrinkage, and other deformation phenomena are accommodated is the primary distinction between a conventional jointed bridge and its jointless counterpart [2]. Traditional jointless bridges allow for expansion and contraction by the movement of the abutments in and out of the backfill, whereas conventional jointed bridges use expansion joints and bearings to separate the superstructure movement from the substructure [3]. Therefore, removing joints alters the mechanism and structural effects of bridge movement rather than eliminating it [4].

Integral, semi-integral, and deck-extension are the three main types of jointless bridges that are frequently seen in the literature [5-6]. Integral bridges rely on the movement of the entire abutment and its supporting piles with bridge movements. This requires the ability of piles to move with the abutment. In cases where an existing jointed bridge is being retrofitted to become jointless, integral abutment bridges (IAB) may not be feasible due to the arrangement of piles in which pile movements are highly restricted (i.e., more than one layer of piles or battered piles exist). Semi-integral bridges (SIAB) offer an important advantage for retrofit applications because the movement of the superstructure is isolated from the piles (i.e., piles are not required to move). In both integral and semi-integral abutments, the expansion of the superstructure results in soil pressures acting behind the backwall or end diaphragm. In deck-extension bridges (DEB), the superstructure movement is similarly isolated from piles, but the backwall is also shielded from bridge movement (i.e., does not move with the bridge, thus soil pressures do not develop behind the backwall due to bridge expansion). The approach slab and the superstructure move together in deck extension bridges.

A semi-integral abutment typically includes an approach slab attached to the bridge deck, an abutment supported on a reasonably rigid foundation, moveable bearings between the end diaphragm and abutment, and an end diaphragm structurally connected to the bridge superstructure [7]. This arrangement enables the superstructure to move relative to the supporting abutment while maintaining a continuous road surface across the bridge end [8]. Since a semi-integral abutment bridge's foundation does not have to offer the same longitudinal flexibility as a fully integral abutment system, the distinction is especially crucial [9].

The seasonal and diurnal temperature changes are of the main sources of movement that a jointless bridge must accommodate. As their temperature fluctuates over daily and seasonal cycles, bridge superstructures repeatedly expand and contract [10-12]. The longitudinal deformation, the coefficient of thermal expansion, the effective expansion length (or tributary length), and the change in bridge temperature can all be used to express the unrestrained

Received: 14 September 2026; **Revised:** 22 September 2026; **Accepted:** 23 September 2026
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DOI: 10.26599/HTRD.2026.9480110
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thermal movement of a bridge [10]. Bearing maintenance and rehabilitation costs can be a major part of the overall maintenance budget, reflecting their relatively shorter service life compared to other bridge components [13]. The bearings are essential for proper bridge performance, since they accommodate movements that would otherwise impose additional forces on the structure [13]. With increasing service life, bearing issues may gradually increase [14]. Field investigations of SIAB in Iowa confirmed multiple instances of bearing-related problems at abutments [15].

Cyclic earth pressures, soil densification, ratcheting, and settling behind the abutment can result from repeated expansion and contraction in IAB and SIAB. The DEB includes a gap between the superstructure and the inner face of the backwall to accommodate expansion and contraction, and a sliding/moving interface between the top of the backwall and the bottom of the approach slab [16].

2 Problem statement and research objectives

Although the SIAB configuration eliminates expansion joints at the bridge ends, the bearing system remains a potential long-term maintenance issue. Changes in bearing condition caused by wear, contamination, deterioration, or other factors can restrict free (unrestrained) thermal expansion and contraction. Bearings are discrete bridge components that require inspection, maintenance, and/or replacement during the service life of a bridge.

An important consideration is the interaction between thermal movement and the backfill soil behind the abutment. When the moving end of the bridge engages the backfill soil during thermal expansion, soil resistance would develop in addition to any resistance associated with the bearing or sliding system. Repeated expansion and contraction result in cyclic interaction between the bridge and the backfill soil. This interaction can generate additional horizontal forces and may contribute to changes in the condition of the backfill over time. The combination of soil and bearing forces impose additional stresses on the superstructure during thermal movement.

These limitations suggest that an alternative mechanism for movement may potentially improve the performance and simplify the configuration of semi-integral bridges. A system that eliminates the conventional bearings while allowing the superstructure to slide relative to the abutment could reduce the number of mechanical components required to accommodate thermal movements. Furthermore, if the moving end diaphragm could be separated from the backwall by a predetermined gap, thermal movements could occur without direct engagement between the diaphragm and the backfill soil.

This study proposes a sliding semi-integral abutment (SSIA) system incorporating the deck extension concept as a bearing-free alternative to conventional semi-integral and deck extension abutments. The proposed system is derived from the semi-expansion concept used by the Wisconsin Department of Transportation (WisDOT) over the last six to seven decades, which replaces the conventional bearing system with a thin, low-friction sliding interface between the end diaphragm and the abutment seat. Through this interface, the end diaphragm, which is connected to the bridge superstructure, can move longitudinally relative to the abutment to accommodate thermal movements. The proposed system also incorporates a shortened backwall and deck extension, allowing the underside of the deck extension/approach slab to slide over the top of the backwall. A predetermined gap is provided between the inner face of the shortened backwall and the end diaphragm to accommodate longitudinal movement. This gap may be filled with a compressible material. In addition to introducing the SSIA concept and its key design features, this study experimentally evaluates and compares polyethylene (PE) and ultra-high-molecular-weight polyethylene (UHMW) sheets as potential low-friction sliding materials for the proposed system. Fig. 1 illustrates the proposed SSIA configuration [17].

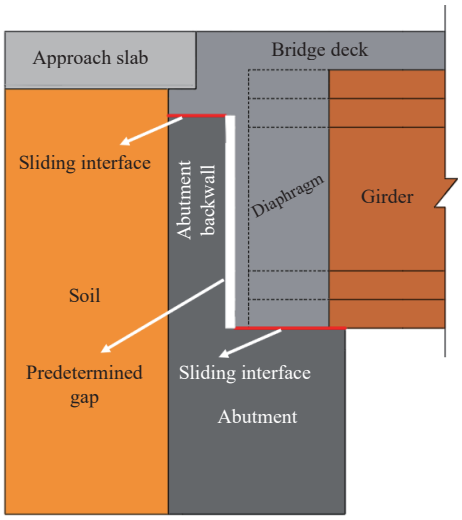


Fig. 1 Schematic concept of sliding semi-integral abutment bridge system.

The feasibility of this concept depends on the frictional characteristics of the sliding interface. A sufficiently low and stable coefficient of friction is necessary to permit thermal movement with limited horizontal resistance. Polyethylene sheets are currently used by WisDOT as sliding material in WisDOT's semi-expansion abutments and therefore provide relevant baseline material. UHMW was investigated as a potential alternative because of its favorable frictional and wear characteristics. An experimental program was conducted to characterize and compare the sliding behavior of PE and UHMW under controlled normal loading and cyclic horizontal displacement. The primary objective of this study was to develop and experimentally evaluate a bearing-free sliding semi-integral abutment system capable of accommodating longitudinal thermal movement through a low-friction interface.

3 Proposed sliding semi-integral abutment with deck extension

The proposed sliding semi-integral abutment (SSIA) concept combines elements of a semi-expansion abutment (WisDOT practice) and a deck-extension system by maintaining a continuous bridge deck over the abutment while introducing a dedicated low-friction sliding interface between the end diaphragm and abutment. WisDOT's semi-expansion detail can - by its basic function - be categorized as a special type of semi-integral abutment system. But it is clearly a distinct and different form in the way the relative movements between the superstructure and substructure are accommodated. While physical bearings are typically used to accommodate relative longitudinal and transverse thermal movements in SIABs, these movements are handled through a thin sliding surface formed between the abutment and the superstructure. In WisDOT practice, the sliding surface is formed with multiple layers of polyethylene sheeting with a total thickness of at least 0.030 inches or 30 mils [18].

Fig. 1 illustrates the proposed SSIA configuration. The end diaphragm remains structurally connected to the bridge superstructure and extends toward the abutment. A low-friction sliding material is placed between the bottom surface of the end diaphragm and the supporting surface of the abutment. Unlike a conventional SIAB, a bearing is not provided between these components. Thus, the longitudinal movement associated with thermal expansion and contraction is accommodated by relative sliding. A shortened backwall is retained behind the end diaphragm. A predetermined gap is provided between the backwall and end diaphragm to ensure that the moving diaphragm does not directly contact the backwall during the anticipated thermal movement. The gap may be filled by

compressible filler materials. The backwall consequently remains substantially stationary while the end diaphragm moves relative to the abutment.

The proposed configuration separates two functions that are commonly coupled at the bridge end: soil confinement and thermal movement accommodation. The retained backwall continues to retain the approach fill, whereas the end diaphragm is allowed to move independently through the sliding interface. This separation is a fundamental feature of the proposed system.

The principal difference between the conventional SIAB and the proposed SSIA is the mechanism used to accommodate longitudinal movement. By eliminating conventional bearings, in the proposed system, thermal movements are achieved through a sliding interface which may be continuous (covering the entire top surface of the abutment or discontinuous covering areas under the girder only with gaps in other areas). A second important difference is the relationship between the moving end diaphragm and the backwall. In the conventional SAIB configuration, thermal movement can cause the moving end diaphragm to interact with the backfill. In the proposed system, the backwall is shortened and separated from the end diaphragm by a predetermined gap. Thus, the backwall remains available for backfill support without becoming part of the longitudinal thermal movement mechanism. Table 1 compares the SIAB, DEB, and proposed SSIA configurations for bridge retrofit applications.

The longitudinal thermal movement of the bridge superstructure can be expressed as Eq. (1):

$$\Delta L = \alpha L \Delta T \tag{1}$$

where, ΔL is the longitudinal thermal movement; α is the coefficient of thermal expansion of the bridge material; L is the effective bridge length contributing to movement at the bridge end (tributary length); ΔT is the change in effective bridge temperature. For the proposed SSIA, the calculated thermal movement determines the required sliding capacity and the minimum clearance between the end diaphragm and backwall. The available sliding surface must be sufficient to accommodate both expansion and contraction without loss of contact between the sliding surfaces. Similarly, the predetermined gap must remain sufficient to prevent contact between the end diaphragm and retained backwall throughout the anticipated movement range. The FHWA report no. RD-03-056 [2] recommends amplifying the calculated deformation (Eq. 1) to account for multiple uncertainties in calculating ΔL. These factors will account for uncertainties associated with the effective temperature range, coefficient of thermal expansion, creep and shrinkage, and restraint effects from abutments and piers.

The sliding interface is a crucial component of the proposed system. It must resist the vertical reaction while permitting repeated longitudinal displacements. To reduce stress in superstructure and substructure elements, the material should provide low friction while maintaining sufficient dimensional stability and resistance to wear under sustained compressive loading. In the present study, layers of PE and UHMW were investigated as the sliding surface. The sliding material should be installed over a sufficiently smooth and even supporting surface. Surface irregularities can affect the contact pressure distribution and frictional response and may also accelerate localized wear and deterioration. Proper surface preparation and secure placement of the sliding material are therefore important construction considerations. The interface should also be protected from contamination by soil, concrete fragments, or other debris during construction and throughout service. Contamination or surface deterioration could increase friction and reduce the ability of the system to accommodate thermal movement.

Retention of a shortened backwall is an important feature of the proposed concept. Rather than completely removing the backwall during retrofit applications, the existing structure can be modified to provide sufficient clearance for the new deck/end diaphragm. This approach maintains the primary soil-retaining function of the abutment while reducing the amount of modification required to accommodate thermal movement. The gap between the end diaphragm and backwall must be designed based on the expected maximum longitudinal movement from the end of construction. The existing abutment backwall must be in good condition and maintain adequate structural capacity after modification to resist friction forces at the top of the shortened wall. Its ability to retain the backfill and resist applicable loads should be verified independently of its role in thermal movement accommodation. The proposed SSIA concept has potential for bridge rehabilitation and new construction.

4 Experimental program and results

The experimental program was developed to characterize the frictional behavior of candidate sliding interface materials under combined normal loading and cyclic horizontal displacement. The primary objectives were to (1) determine the static and dynamic coefficients of friction of the sliding interfaces, (2) compare the performance of PE sheets currently used in WisDOT semi-expansion details with UHMW sheets, and (3) obtain experimentally based friction parameters for subsequent evaluation of the proposed SSIA system.

To properly represent the contact surfaces of an actual bridge abutment, half-scale (compared to typical bridge abutments) reinforced concrete specimens were fabricated. The specimens represented a portion of the bridge abutment seat and girder, with the sliding material placed between the two concrete surfaces. The experimental program subjected the specimens to sustained vertical compressive forces while cyclic horizontal displacements were imposed at the sliding interface. This loading configuration was intended to represent the basic mechanical conditions experienced by the sliding interface during repeated thermal expansion and contraction of a bridge.

Two reinforced concrete specimens were used to form the mating surfaces of the bridge superstructure and abutment. Each specimen had nominal dimensions of 61 cm × 61 cm × 61 cm (2 ft × 2 ft × 2 ft), providing a representative contact area for the sliding interface while allowing the specimens to be tested using the available laboratory loading system. The bottom surface of the interface was a steel troweled surface while the top surface was cast once the interface sheets were placed over the bottom surface.

The first sliding material investigated was the PE sheeting representing the material currently used in the WisDOT “semi-expansion” abutment detail. Therefore, three layers of 10-mil (0.25 mm) PE sheets were placed between the concrete specimens. UHMW was investigated as an alternative sliding material. Three 1/16-in. (1.59 mm) UHMW sheets were used to form the interface. The ma-

Table 1 Characteristics of conventional SIAB, DEB, and proposed SSIA for bridge retrofit applications.

Characteristic	Conventional SIAB	DEB	Proposed SSIA
Expansion joint	Eliminated	Eliminated	Eliminated
Bridge end	Supported on movable bearings	Supported on movable bearings	Supported on sliding interface
Conventional bearings	Required	Required	Eliminated
Thermal movement mechanism	Movement of bearing	Interface sliding	Interface sliding
Backwall	Replaced with moving end diaphragm	Retained but shortened	Retained but shortened
Direct diaphragm-backfill interaction	Expected during thermal expansion	Prevented	Prevented

terial was selected because of its potentially lower coefficient of friction and improved wear and abrasion resistance compared with conventional PE. UHMW was intended to evaluate whether a lower-friction interface could be developed to improve the performance of the proposed system. According to ASTM D4397 [19], the PE sheeting should have a minimum tensile strength of 1 700 psi (11.7 MPa) in the longitudinal direction, while the UHMW polyethylene has a typical density of 0.93–0.94 g/cm^3 and tensile strength of 4 000–6 000 psi (27.6–41.3 MPa).

A custom reaction frame was designed and constructed for these tests, as shown in Fig. 2. The test frame consisted of two steel columns, a cantilever steel beam, and diagonal steel braces that formed the loading system. The frame was anchored to the laboratory strong floor using high-strength threaded anchor rods. Two independently controlled hydraulic actuators were used to apply the required loading conditions. A vertically oriented hydraulic jack was positioned above the upper concrete specimen and applied the prescribed normal force to the center of interface. The vertical load represented the compressive reaction transferred from the bridge superstructure to the abutment. A second hydraulic jack was connected horizontally to the lower concrete specimen. This actuator imposed cyclic longitudinal displacement across the sliding interface, representing the relative movement between the bridge superstructure and abutment. The horizontal actuator was aligned with the sliding interface to minimize eccentricity and unintended rotational effects during testing. The applied vertical load and generated horizontal load were monitored using load cells, while the applied displacements were measured using two displacement transducers placed at the two edges of the specimens.

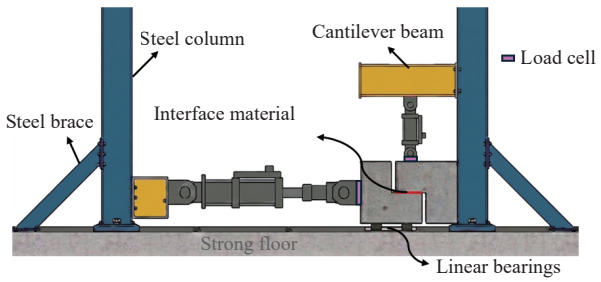


Fig. 2 Schematic view of the utilized test setup.

The lower (moving) concrete block was supported on four high-capacity, low-friction industrial bearings (two linear systems consisting of two bearings each). The bearings allowed the specimen to translate horizontally while minimizing resistance unrelated to the sliding interface under investigation. Accordingly, the measured horizontal force primarily represented the frictional resistance developed between the sliding material and the opposing concrete surfaces. A simple pull-out test on the industrial bearings indicates that the friction coefficient for the bearings under the lower block was less than 0.03.

The PE interface was tested under three different normal force levels: 33.4 kN (7.5 kips), 66.7 kN (15 kips), and 100 kN (22.5 kips). The UHMW interface was tested under a normal force of 66.7 kN (15 kips) only. All test results are reported in the WisDOT report No. 0092-25-02 [20]. Here results of tests for normal force of 66.7 kN (15 kips) are presented. For each interface material, the same displacement-controlled cyclic loading protocol was applied. The horizontal loading consisted of nine fully reversed displacement cycles. The test began with three cycles at a displacement amplitude of ± 1.27 cm (± 0.5 in.), followed by three cycles at ±1.905 cm (± 0.75 in.), and concluded with three cycles at ±2.54 cm (± 1.0 in). The progressive increase in displacement amplitude allowed the interface response to be evaluated over a range of sliding displacements while also providing information regarding the frictional response under cyclic movement.

For each test, the static coefficient of friction was calculated from the maximum measured horizontal force associated with the initiation of sliding, as shown in Eq. (2):

$$\mu_s = \frac{F_{max}}{N} \tag{2}$$

where, μ_s is the static coefficient of friction; F_{max} is the maximum horizontal friction force; N is the applied normal force. The dynamic coefficient of friction was calculated using the average horizontal friction force measured during the steady-sliding portion of each loading cycle, as shown in Eq. (3):

$$\mu_d = \frac{F_{avg}}{N} \tag{3}$$

where, μ_d is the dynamic coefficient of friction; F_{avg} is the average horizontal friction force during steady sliding. The use of both static and dynamic coefficients allowed the interface behavior to be characterized from the initiation of movement through sustained sliding.

The results of the experimental program for a normal force of 66.7 kN (15 kips) are shown in Table 2. The coefficient of friction for the UHMW interfacial layer is lower and, based on the other properties of that material compared to PE, UHMW might be a compelling candidate interface material for the proposed SSIA bridges.

The force-displacement results for the PE and UHMW sheets under a normal force of 66.7 kN (15 kips) are shown in Fig. 3 and Fig. 4, respectively. The initial results indicated that UHMW can deliver reliable performance across repeated temperature cycles. An examination of the UHMW sheets after tests indicated no damage to the sheets. Only slight damage was observed on the PE sheets. UHMW can potentially be a tougher and more durable sliding material in the proposed SSIA system.

Table 2 Results of the experimental program under a normal force of 66.7 kN (15 kips).

Parameter	PE	UHMW
Thickness (mm)	0.76	4.76
Normal force (kN)	66.7	66.7
Static μ_s	0.25	0.17
Dynamic μ_d	0.17	0.12

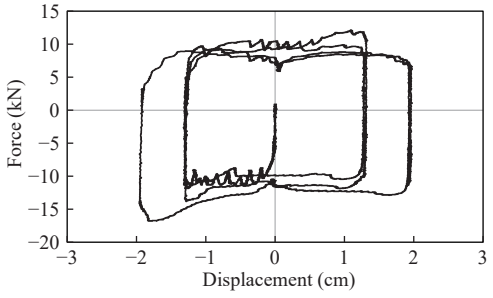


Fig. 3 Force vs. Displacement of PE sliding interface.

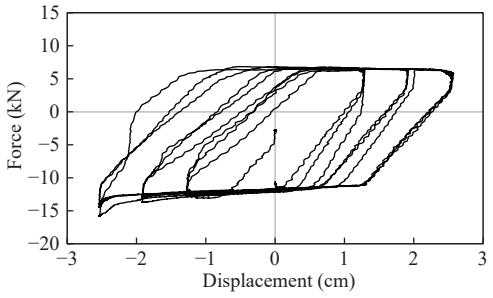


Fig. 4 Force vs. Displacement of UHMW sliding interface.

5 Applicability and design implications of the proposed system

The experimental results introduce several considerations for the design and implementation of the proposed SSIA system. Since thermal movement is accommodated through interface sliding, the design must consider available movement capacity, interface friction, and contact pressure. The available (obstruction-free) sliding distance should be sufficient to accommodate the anticipated longitudinal thermal movement without causing contact between the end diaphragm and the retained backwall or other obstacles (such as wing walls). The required movement capacity can be established from the expected bridge temperature range (including the amplification factors proposed in the FHWA report [2]) for effective expansion length of the bridge (or length tributary to the abutment).

Considering skewed bridges, transverse deformation would also be expected under temperature variations in addition to longitudinal deformation. Since the gap between the end diaphragm and backwall is intended to accommodate longitudinal deformation, transverse deformation should also be considered and accommodated. If shear pockets (keys) are utilized between girder seats, sufficient gaps must be provided along the longitudinal and transverse surfaces of the pocket to allow movement. The diaphragm would then be placed on the top surface of the abutment (over the sliding surface) with a corresponding pattern of pockets or shear keys. A gap in the longitudinal faces of any pocket should provide sufficient space to accommodate transverse deformation. A compressible filler material could be used in the gap throughout the service life of the bridge. The required gap size would depend on the bridge geometry and the expected transverse deformation under temperature variations. Fig. 5 shows the accommodation of transverse movements when shear key pockets are incorporated into the abutment surface.

In addition to movement capacity, the horizontal resistance generated by the interface is a key design parameter. The friction force can be expressed as Eq. (4):

$$F_f = \mu N \tag{4}$$

where, F_f is the interface friction force; μ is the coefficient of friction; N is the normal force. For a given vertical reaction force, the measured coefficient of friction can be used to estimate the horizontal resistance that must be overcome before and during thermal movement.

The comparison between PE and UHMW indicates that material selection can influence the resistance of the sliding interface. For bridge applications, however, initial friction alone should not govern material selection. The selected material must maintain its sliding characteristics under sustained compression and repeated movement. Wear, environmental exposure, moisture, contamination, temperature, and aging may alter the interface behavior over time. These factors should be evaluated before establishing a long-term design coefficient of friction.

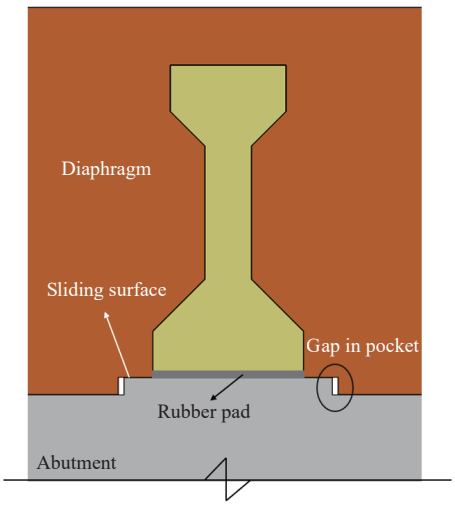


Fig. 5 Concept of pockets for transverse deformation (cross-sectional view).

The sliding interface should be designed as an engineered bridge component rather than treated simply as a construction layer. Uniform contact between the polymer and supporting concrete is important because localized pressure concentrations may affect both friction and material durability. The supporting surface should consequently be sufficiently smooth and level, and the sliding material should be installed without folds, wrinkles, or discontinuities. The interface should also be protected from construction debris and long-term contamination.

The proposed configuration may be particularly attractive for rehabilitation of existing jointed bridges. The concept does not require complete removal of the existing backwall during retrofit; instead, the backwall can be modified to provide the required clearance for the moving end diaphragm, if the existing condition and strength of backwall allow its repurposed role. This approach may reduce demolition and allow a greater portion of the existing abutment to remain in service.

6 Conclusions

This paper presents a concept for a sliding semi-integral abutment (SSIA) bridge with deck extension as an alternative approach for jointless bridges. This concept is derived from the Wisconsin Department of Transportation's "semi-expansion" detail [18], which employs a PE sliding interface. Unlike conventional semi-integral abutment bridges, which rely on physical bearings to accommodate longitudinal superstructure movement, the proposed system replaces the conventional bearing with a low-friction sliding interface between the superstructure and abutment. The proposed configuration also retains an abutment backwall and introduces a gap between the inner face of the backwall and the end diaphragm. This arrangement separates the backfill soil from the thermal movement of the superstructure and is intended to prevent direct engagement between the moving end diaphragm and backfill during the anticipated range of thermal movement. An experimental program was conducted to characterize and contrast the frictional behavior of PE and UHMW interfaces under controlled normal loading and cyclic horizontal displacement. The UHMW interface exhibited favorable sliding behavior under the investigated loading conditions and demonstrated a lower measured coefficient of friction relative to the PE interface. The experimental observations support the use of UHMW as a promising candidate for the sliding interface of the proposed SSIA system.

The proposed system has several potential advantages, including elimination of conventional bearings, reduction of direct soil-structure interaction associated with thermal movement of the end diaphragm, and reduced modification of the existing abutment during retrofit construction.

Overall, the results demonstrate the feasibility of using a low-friction sliding interface as an alternative to conventional bearing systems for accommodating thermal movement in a semi-integral bridge configuration. The proposed SSIA concept provides a promising basis for further development of bearing-free jointless bridge ends. Future research should focus on long-term cyclic performance, environmental conditioning, temperature effects, contamination, wear, full-scale testing, and field implementation to establish the durability and reliability required for practical bridge applications.

Acknowledgements

None.

Funding

Funding for the experimental program was provided by the Wisconsin Highway Research Program (WHRP) under Project 0092-25-02. The opinions expressed are those of the authors only and not necessarily those of the sponsor.

Declaration of competing interest

The authors declare that they have no competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Author contribution statement

Farhad Farajiani: conceptualization, data curation, funding acquisition, methodology, software, writing-original draft, writing-review & editing. Habib Tabatabai: data curation, investigation, methodology, software, writing-original draft.

Data availability statement

None.

Use of AI statement

None.

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