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Bridge Decks Going Jointless

Cementitious Composites Improve Durability of Link Slabs

Most highway bridge construction in the U.S. involves multiple span steel or prestressed concrete girders supported at piers or bents. At each end of the spans, expandable mechanical joints are installed to permit bridge deck movement and deformations due to concrete shrinkage, temperature variations, and girder deflection. An expansion joint system should provide smooth rideability, low noise level, wear resistance, water tightness, and resistance to snow plow damage.

For the past 40 years increased traffic loads, traffic volumes, and normal bridge movement have adversely affected bridge expansion joint system performance with failure often in one or more of the areas stated above. The deterioration of the bridge deck near the joints results in cracking of the concrete, which leads to decreased water tightness on the bridge deck and the underlying substructure. Negative economic impacts of the deterioration of these joints have created interest in the development and advancement of the jointless bridge deck concept.

Jointless History

Jointless bridges have been built in the U.S. since the 1930's using design and construction procedures developed from the success of field prototypes. A major goal in bridge deck research has been to develop a cost effective solution to the problem of bridge deck deterioration around the joints. Research in jointless bridge deck construction aims to accomplish four desirable design objectives: (1) Long-term serviceability; (2) minimal maintenance requirements; (3) economical construction; and (4) improved overall performance.

Research by Alampalli and Yannotti (1998) found that the jointless bridge deck construction process is more efficient than the common integral bridge construction practice. Reporting on the field inspection of 105 jointless bridge decks, the decks functioned as designed with the exception of minor deck cracking. While additional improvements in the jointless bridge deck construction process were recommended by Alampalli and Yannotti, they found that jointless decks generally performed better than decks with joints.

Introduction of the Link Slab

A jointless bridge deck is created by the replacement of the expandable mechanical joint with a slab of deck material, typically called a link slab (see figure 1).

Under typical traffic and environmental conditions, forces on the bridge deck subject link slabs to bending and axial elongation strain, i.e. pushing and pulling apart. Axial elongation strain is imposed on the link slab due to shrinkage, creep, and thermal expansion of the spans. Cracks form to accommodate elongation strain in the material. Controlling crack development and crack width in the link slab is critical for

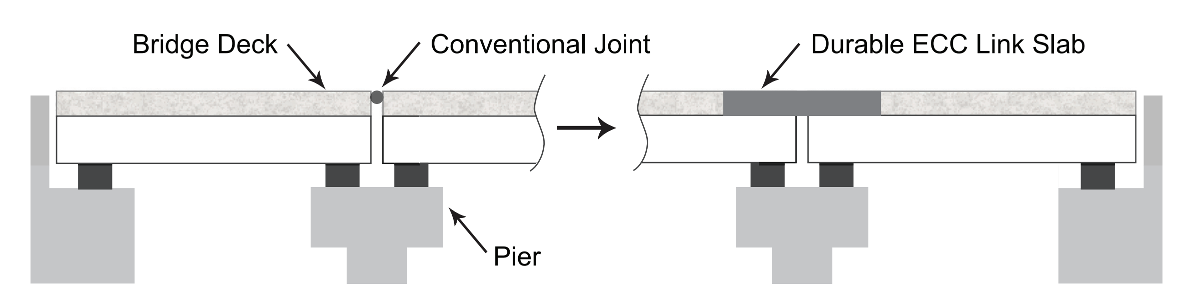


Figure 1. A Conventional Joint vs. a Durable ECC Link Slab.

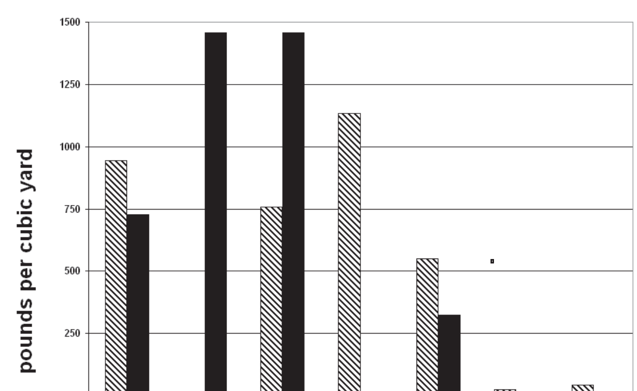
link slab survivability. This research focuses on using materials in the link slab construction that control cracks, allow bridge movements, and are easy to use in the field.

ECC Material Design

A team of researchers from the University of Michigan, led by Dr. Victor C. Li at the Advanced Civil Engineering Material Research Laboratory, experimented with cementitious composites in the construction of durable link slabs for jointless bridge decks (Li,2003).

Engineered Cementitious Composite (or ECC), is a high performance fiber reinforced cementitious composite (HPFRCC) with superior ductile properties designed to resist tensile and shear forces while retaining the most desirable properties of conventional concrete in all other respects (Li, 2002). The ductile properties give the ECC its ability to plastically deform without breaking or fracturing.

ECC and conventional concrete use many of the same raw materials (see Figure 2). A key additional ingredient in ECC is poly-vinyl-alcohol (PVA) fiber, which allows the ECC to be more ductile and therefore more durable than conventional concrete. The PVA fiber used in ECC is designed with a surface coating that controls interface debonding when ECC is subjected to excessive tension.



	Cement	Gravel	Sand	Fly Ash	Water	SP	PVA Fiber
M45	945	0	757	1134	551	23.60	43.80
Concrete	728	1456	1456	0	324	7.25	0.00

Figure 2. Mix Proportions (lb/yd^3) for ECC Sample M45 and Concrete

The Shrinkage Factor

To characterize the tensile behavior of ECC, 12" x 3" x 0.5" samples were subjected to a one-dimensional tensile stress test. Test configuration details were according to previous work by the principle researcher (Li et al, 2001). The sample ECC material exhibited excellent fresh workability, which eliminated the need for vibration to remove air voids.

When the ECC M45 mixture was air cured, it yielded a compressive strength of 8700 psi; well above the acceptable bridge deck specification requirements of 4500 psi. Tests on the ECC M45 samples after curing for 3- and 6-months resulted in a 3.0% tensile strain capacity, which is about 300 times that of normal concrete and exceeds tensile strain loading calculated during the link slab structural design.

To estimate the shrinkage deformations and the durability of the steel-reinforced ECC link slab, the shrinkage properties of ECC were investigated according to ASTM C157/C157M-99 and ASTM C596-01standards.

Drying shrinkage strain of the ECC M45 sample was found to be approximately twice as high as that of the control concrete. This was due to the high cement and water content per volume in the ECC M45 sample, which was twice that of the reference concrete (see Figure 2).

For the climate in Michigan, the total drying shrinkage strain was found to be approximately 0.10%, far below the tensile strain capacity of ECC (~3%) and therefore prevents the formation of tension-softening restrained shrinkage cracks commonly observed in normal concrete.

The usage of low-alkali cement in the ECC to reduce drying shrinkage was not found to be an advantage over ordinary portland cement.

The average drying shrinkage crack widths found in ECC samples ($3.0x10^{-3}$ inches) were one order of magnitude smaller than the reference concrete samples ($4.0x10^{-2}$ inches). These small crack widths in the ECC link slab improve the durability by reducing the permeability, thereby increasing water tightness.

This is significant in the snowbelt states where an estimated twelve million tons of deicing agents are used annually. When these agents are applied to bridge decks, aggressive corrosives can penetrate leaking joints and lead to deterioration of the deck and support structure.

The Freeze-Thaw Factor

Freeze-thaw durability is a major concern with the ECC link slab. Air entrainment, which is achieved by using an admixture to incorporate air bubbles into conventional concrete, increases freeze-thaw durability. Air-entrained concrete has a series of air voids trapped in it. The spacing and size of the air voids is critical to freeze-thaw resistance. Previous research has found that air voids between $0.8x10^{-5}$ and $1.4x10^{-5}$ inches in diameter are most advantageous in ECC material. In addition, the dispersion of these air bubbles in fresh concrete or ECC makes it more workable than non air-entrained concrete. By examining the pore structure within the sample ECC, it was found that the mix design of the material resulted in a microstructure which showed no damage under freeze-thaw cycles, even without the deliberate use of air entrainment as typically required for concrete used in Michigan.

Tests to simulate the freeze-thaw cycle were conducted on the samples according to ASTM C666 Procedure A. In this procedure the test material is frozen (0°F) and thawed (40°F) in water during a three hour cycle. When thawed, moisture seeps into cracks and then expands during freezing. After thawing, it seeps further, re-freezes and then expands, repeating the cycle. During 300 freeze-thaw test cycles conducted over a 14 week period, regular non-air-entrained concrete failed after 110 test cycles and lost an average of 2.0% of initial mass. The ECC samples survived all 300 test cycles, exhibiting performance similar to well air entrained concrete and lost an average of only 0.9% of initial mass. The freeze-thaw exposure did not effect the tensile strength, crack width, or strain capacity of the ECC samples.

Where the Slabs Meet

The link slab interface is the location on the bridge deck where the concrete deck slab and the ECC link slab are joined. Major interface design concerns are (1) strengthening of the interface between the concrete and the ECC and (2) shifting any concentration of stress away from the interface.

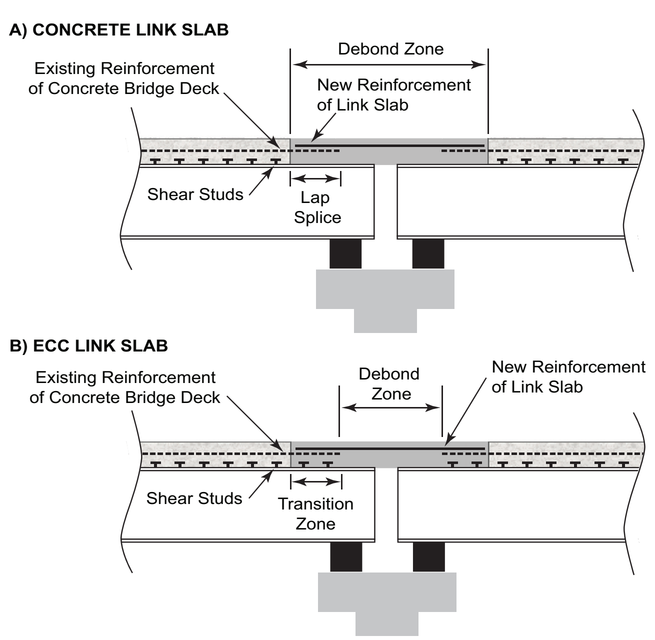


Figure 3. Comparison Between Conventional Method (A) and Proposed Improved Method (B) in the Design of the Link Slab Interface.

Present concrete link slab designs place limited attention on the interface between the deck slab and the link slab. Additional reinforcement is spliced with existing reinforcement to strengthen the conventional concrete link slab (see Figure 3A). In this design, the interface becomes the weakest part of the bridge deck system.

Improvements in the interface design of an ECC link slab were investigated using numerical structural analysis. The result of extending shear studs into the ECC link slab (see Figure 3B) was a 80% decrease in the maximum tensile stress compared to the conventional concrete link slab design. The addition of the shear studs shifted the peak stress from the interface into the bulk part of the link slab. This shift reduced the likelihood of deterioration because it distributed the highest stresses over a larger area of the ECC link slab and minimized stress at the interface. In addition, minimum reinforcement splice lengths were investigated to prevent undesirable cracking at the interface or failure as a result of pullout of the reinforcement bars.The existing AASHTO lap splice length requirement for reinforcing bars was found to be adequate for rebar within ECC material.

Due to the physical differences between ECC and concrete, standard tests specifically designed for concrete are not directly applicable to ECC testing. This was the case with the pullout behavior testing that was used to determine the performance of the reinforcement bars (rebar) embedded within the ECC. ASTM C900 was modified slightly, but the researchers determined the modification did not impact results. The peak loads during the pullout tests were comparable and acceptable for rebar embedded in concrete or ECC. The use of epoxy-coated rebar also showed similar pullout loads.

As forces (or loads) are applied to the bridge deck, they are transferred from the rebar into the surrounding material (i.e. concrete or ECC). The transfer of the forces from the rebar to concrete can result in splitting cracks along the bar and eventual failure of the surrounding concrete. The reinforcement in the ECC demonstrated frictional failure without splitting and cracking of the concrete, thereby exhibiting a more desirable ductile failure mode.

New research sponsored by the National Science Foundation (Keolian et al, 2005) shows that about 40% reduction in cost, CO_2 emissions, and primary energy consumption can be achieved over the life cycle of the bridge by replacing expandable mechanical bridge joints with durable ECC link slabs. Additionally, these slabs may result in longer bridge service life and minimized travel impact on motorists by reducing bridge closings for routine maintenance.

Conclusions

The requirements for a link slab application were satisfied by the hardened properties of the ECC material tested (mixture M45). The ECC demonstrated strain-hardening behavior with an ultimate tensile strain capacity near 3.0%. This is roughly 300 times that of normal concrete. To accommodate this strain, multiple cracks formed with an average crack width of 3.0×10^{-3} inches. This is one order of magnitude smaller than typical concretes. The workability of ECC M45 was suitable for large volume mixing and casting in the field.

Replacement of expansion joints with ECC link slabs can reduce the deterioration of bridge decks. Durability of the ECC link slabs was found to be superior to concrete link slabs despite larger free shrinkage deformations as a result of the tight crack widths developed under tension. These tight cracks resulted in significant reductions in the permeability of the link slab and greatly improve the ECC durability. Freeze-thaw behavior indicates that the ECC M45 mixture provides significant resistance to deterioration during repeated freeze-thaw cycles.

The pullout failure mode of reinforcement in ECC is more ductile with respect to conventional concrete due to the increased ability of the ECC material to plastically deform without breaking or fracturing.

Required AASHTO lap splice length of rebar in concrete was found to be adequate for rebar within ECC material.

Through the implementation of durable ECC link slabs, significant savings can be realized over the life cycle of bridges due in part to the possible decrease in routine maintenance of bridges and their expansion joints.

Contact Information

For more information regarding durable link slabs on jointless bridge decks in Michigan and this study, please contact David Juntunen, Bridge Operations Engineer, at (517) 322-5707 or by e-mail at juntunend@michigan.gov.

An electronic copy of this and past issues of the Research Record, as well as information on Michigan's LTAP programs and publications can be found at www.michiganltap.org or by calling (906) 487-2102.

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