UHPC LINK SLAB SOLUTONS IN NORTH AMERICA

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Abstract

A major concern for bridge owners is bridge deck joints which leak, allowing water and chlorides to spill onto the superstructure and substructure elements, thereby causing corrosion and other surface damage. If the bridge deck has no joints, this problem is eliminated.

A link slab is a cast-in-place continuity slab above the pier cap that connects simply supported adjacent spans. Conventional link slabs tend to produce cracks that are wide enough to allow moisture and chloride penetration, affecting the durability. The strain-hardening characteristic of UHPC with steel fibers is a key component in the development of UHPC link slabs with crack widths so small that moisture and chlorides cannot penetrate the surface, making them very durable. The New York State Department of Transportation (NYSDOT) has designed and used UHPC link slab details on various projects since 2013. This paper discusses the development, design and use of UHPC link slabs, as well as project examples and lessons learned.

Résumé

Les joints de pont existants qui fuient, permettant à l'eau et aux chlorures de s'écouler sur les éléments de la structure et les appuis et y causant corrosion et autres dommages en surface, sont une préoccupation majeure pour les propriétaires de ponts. En l'absence de joints sur le tablier, le problème est éliminé.

Une dalle de liaison est une dalle de continuité coulée sur place au-dessus d'un chevêtre pour connecter des travées adjacentes isostatiques. Les dalles de liaison conventionnelles ont tendance à produire des fissures suffisamment larges pour permettre à l'eau et aux chlorures de pénétrer et d'affecter la durabilité. Le caractère écrouissant du BFUP à fibres métalliques est un facteur clé du développement de dalles de liaison dont la fissuration est si fine que la surface est résistante à la pénétration de l'eau et des chlorures, ce qui la rend très durable. Le Département des Transports de l'État de New York (NYSDOT) a conçu et employé des dalles de liaison BFUP sur divers projets depuis 2013. L'article présente le développement, le calcul et l'emploi de ces dalles de liaison, des exemples de projets et les enseignements qui en ont été tirés.

1. JOINTS ON MULTI-SPAN DECKS

Joints accommodate movement caused by: expansion and contraction due to temperature changes; concrete shrinkage and creep; rotation at supports due to live load deflection; and settlement [1]. Prior to the 1970's [2] it was common practice to design multi-span bridges as single span structures. These spans were simply supported on the piers with joints. This was a simple and effective structural solution [2] but historically, bridge joints have performed poorly, with leakage through the joints causing premature corrosion on girder ends and the supporting structure. Cracking, spalling and deterioration of the concrete deck slab in the vicinity of the joints are all common occurrences, along with spalling of the concrete around the bearing seat and pier cap [2].

2. TYPES OF JOINTS

Each jurisdiction in the US and Canada have their own approved joint systems. For example, the Virginia Department of Transportation (VDOT) uses the following [1]:

- Armored joints (open or sealed);
- Asphalt plug joints;
- Cushion seal (elastomeric expansion dam);
- Finger joints;
- Hot poured sealer /expansion material;
- Preformed Elastomeric Compression Seals;
- Poured (silicone) seals;
- Sliding plate joints;
- Strip seals.

3. PROBLEMS ASSOCIATED WITH JOINTS

The following bridge components are adversely affected by leaking joints [1]: end diaphragms; beam/girder ends; bearings; substructure seat area and other substructure areas.

The cost, installation procedure and expected usage life of the above mentioned joint systems vary widely. The selected system is based on many factors. As previously noted, most of these systems require regular maintenance. Ultimately, the ability to have leak-free expansion joints proves to be almost impossible in the long run.

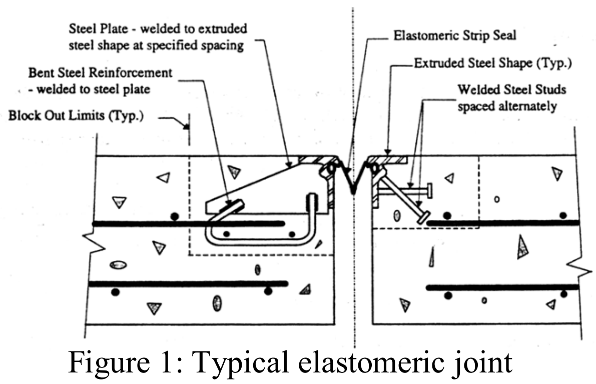

Figure 1: Typical elastomeric joint

Figure 2: Typical joint in service

The durability of commonly used seals is highly problematic [3] (see Figures 1 and 2). In high traffic environments, seals may last less than 1 year, and the cost of traffic control (to allow sufficient re-sealing of joints) continues to increase. Typically, there are three problems that affect the durability of joint seals:

1. Localized failure of the concrete adjacent to the joint
2. Accumulation of grit and debris above the joint seal, causing failure of the seal
3. Debonding of the seal from the adjacent concrete

In many Canadian provinces and U.S. states, the use of de-icing salts on roads and bridges during winter months also contributes to accelerated deterioration. The water will carry the chlorides, which accelerates the corrosion rate of the deck and substructure. Freeze-thaw cycles also increase the cracking and deterioration of concrete. Having leak free expansion joints is the only way to ensure the integrity of our bridges under these challenging conditions.

The two greatest impediments (to facilitate joint elimination) are traffic control and load effects on the piers. In high traffic environments, it is difficult to obtain approval for lane closures of adequate duration for joint eliminations [3]. Hence, it is important to find ways to perform these replacements faster, so that more structures can be repaired. Analyses are required to determine how to modify the bearing systems and verify that the piers can take the additional lateral loads. These are extra steps which require resources and need to be performed before a link slab solution can be implemented.

4. LINK SLABS

Since numerous problems directly related to joints have been experienced over the last 50 years, the potential or future elimination of bridge deck joints is the focus and desire of many owners. For instance, VDOT [3] strives to eliminate 2% of expansion joints each fiscal year. Many owners will review joints and, if modifications can be made to the bearing details to accommodate a joint-free deck, the use of link slabs is being considered.

The Ministry of Transportation of Ontario (MTO) has also reviewed multiple link slab options [2] used in Ontario: haunched deck slabs; flexible link slabs; semi-continuous deck; and debonded link slabs. All have their relative advantages and costs.

5. DESIGN OF CONVENTIONAL CONCRETE LINK SLABS

For conventional concrete link slab designs, both end beams are free to rotate at the pier. The goal is to debond the deck from the beam, usually on approximately 5% of the span length. Shear studs in the debonding area is eliminated and more are added in the tension zone. When the beam rotates, this creates tension in the link slab. Reinforcement is added to the link slab to limit cracking. To achieve debonding, a bond breaker gasket between the supporting beams and the link slab is provided. A typical link slab needs to be in the range of 3 to 4.5 m wide to achieve the proper development (see Figure 3).

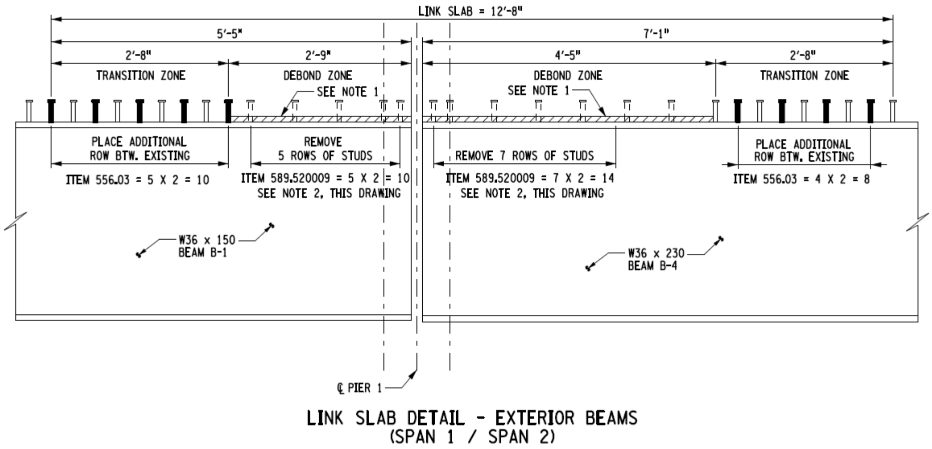

Figure 3: Typical link slab detail

6. NYSDOT DESIGN APPROACH FOR UHPC LINK SLABS

The NYSDOT Office of Structures has developed an innovative UHPC link slab design utilizing ultra-high performance concrete (UHPC), with a desire to eliminate transverse deck joints wherever feasible (see Figure 4). Based on analysis that considered the distribution of strain due to girder end rotation, it was determined that transition will occur at the bearings. The force required to strain UHPC in pure tension is extremely large and fixity pins in fixed bearing will yield, long before generating enough force to elongate the UHPC. Therefore, the link slab design assumes that the UHPC section is subject to bending only. The link slab also acts as a semi-rigid link between spans transferring compressive, tensile, and shear stresses due to horizontal loads.

UHPC is capable of developing ultimate tensile strains up to 0.007, by the formation of micro cracking. A maximum design strain of 0.0035 at the extreme tensile fibre was chosen in order to control the crack width. The crack spacing associated with a strain of 0.0035 is approximately 5 mm, resulting in extremely fine cracks that are virtually invisible to the naked eye. Limiting the tensile strain will increase the service life of the link slab by preventing the penetration of moisture and chlorides (see Figure 5).

Design of the UHPC link slab is influenced by variables such as span arrangement, bearing type and arrangement, girder end rotation due to live load, and bridge skew. The following guidance is provided to help ensure proper structural functioning of the bridge as a system and durability of the UHPC link slab.

6.1 Span Arrangement

The span arrangement shall be such that the overall bridge expansion and contraction is accommodated. Link slabs at intermediate supports with integral/jointless abutment detail is the best possible combination, followed by link slabs at the interior supports with a joint at one abutment and a jointless deck at the other. For long span bridges, which need more than one joint to accommodate thermal movement, link slabs at the interior supports and joints at both abutments are preferred. Joints at intermediate supports are unavoidable for long bridges with a large number of spans where thermal movements are too large to be accommodated by expansion joints at the abutments alone.

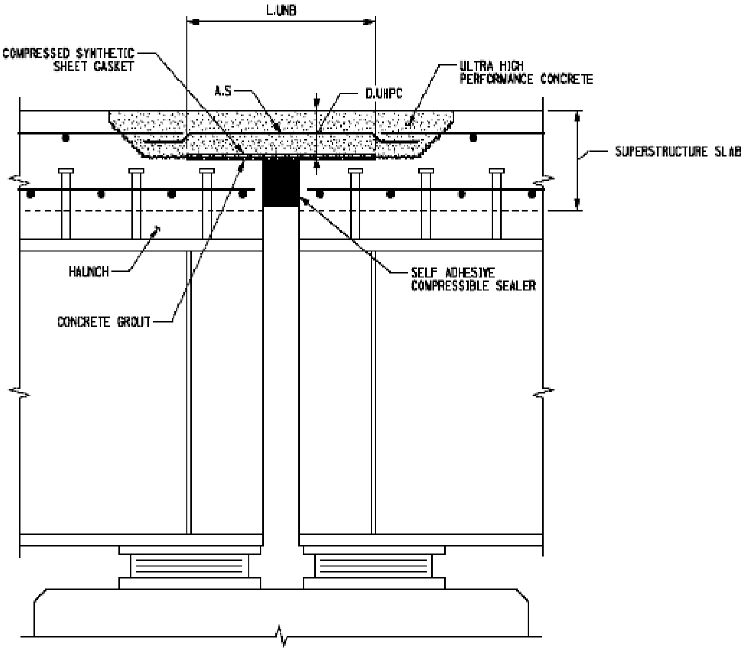

Figure 4: UHPC Link Slab Cross Section

6.2 Bearing Type & Arrangement

Link slabs shall not be used with two lines of fixed bearings on intermediate supports. Furthermore, steel rocker bearings, as well as steel sliding bearings, are unsuitable for link slabs due to the repetitive horizontal movement induced by girder live load deflections.

6.3 Rotation Demand

The main function of the link slab is to provide continuity of the deck slab yet offer negligible resistance against the girder end rotation. It is intended to act as a pinned connection within the deck slab. The UHPC link slab shall be designed to allow for the rotation due to the factored live load deflection of the superstructure without exceeding a maximum strain of 0.0035 in tension and a maximum stress of 100 MPa in compression. A standard link slab thickness of 100 mm may be used, leaving only the unbonded length to design based on these strain and stress limitations.

For computation purposes, the modulus of elasticity of the UHPC may be taken as 55 GPa and the UHPC tensile cracking stress shall be taken as 8 MPa.

6.4 Reinforcement

Due to the steel fibers present in UHPC, conventional reinforcing bars are not required within the link slab for strength. However, to improve the overall toughness of the system, one layer of longitudinal reinforcement is provided in the center of the link slab. The size, spacing, and type should match that of the adjacent concrete deck.

6.5 Anchoring of Link Slab

The portion of the link slab beyond the unbonded length is used to anchor it into the concrete deck slab. The concrete deck slab in this region shall be roughened to amplitude of 13 mm. An exposed aggregate surface can be used to obtain the required roughness for new decks, precast or cast in place. Reinforcing bars from the concrete deck shall extend into the link slab to a sufficient embedment length to establish a proper connection between the link slab and the deck. Link slabs shall only be used with new decks, or existing decks that are in fair condition.

6.6 Restrictions on Skew

Due to limited experience with UHPC link slabs, its usage is limited to supports not exceeding a skew of 30 degrees.

Figure 5: Finished Link Slab

7. EXAMPLES OF NYSDOT UHPC LINK SLAB APPLICATIONS

New York was one of the first states in the US to use UHPC on their bridge projects. Finding innovative ways to take advantage of UHPC performance led to the development of UHPC link slabs. While performing the deck replacement for a project on Route 17 in Owego, NY, a UHPC link slab was also used as part of the retrofit. This was performed in 2013 and the detail used is provided in Figure a [3]. The bearings under the steel girders are designed to allow both rotation and longitudinal movement (see Figure 6).

The list of NYSDOT UHPC link slab projects is given in Table 1.

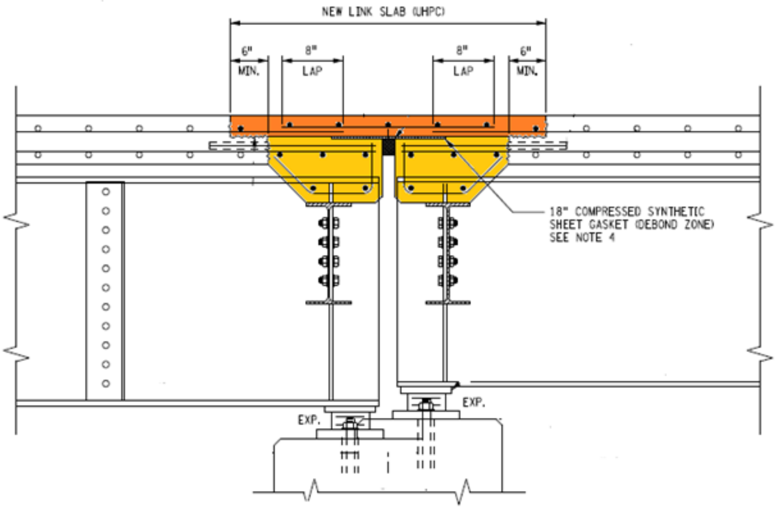

Figure 6: Latest NYSDOT link slab detail, 2016

Table 1: NYSDOT UHPC Link Slab Project List

2013	D262100	I-84 over Dingle Ridge Road, 2 bridges x 2 link slabs each
	D262030	Route 962G over Route 17, town of Owego – 1 link slab
	D262213	Route 104 EB over Route 590 – 2 link slabs
2014	BIN 3358710, BR-1201 (Broome C^{ty})	Hooper Road over Route 17C – 2 link slabs
2016	D262985	188th Street, New York - 2 link slabs
2017	D263109	Brook Avenue over NY 27 (Long Island) - 3 link slabs
		NY 25 EB over NY 135 (Long Island) - 3 link slabs
		Deer Park Avenue over NY 27 (Long Island) - 5 link slabs

8. LESSONS LEARNED AND CONCLUSIONS

UHPC link slabs are proving to be a very efficient, long term solution for the elimination of joints. Owners and designers have many options to consider, in order to effectively and economically maintain and preserve existing structures. One approach is to maintain joints systematically, year after year, by replacing all the critical components at regular intervals. In reality however, owners are faced with many challenges and elimination of the joint is the best long term proven approach. Using a UHPC link slab allows long term, virtually maintenance-free performance, compared to link slabs designed with conventional concrete. The size of the joint, amount of reinforcing and long term durability of the UHPC option provides a viable alternative which will certainly see more usage across the US and Canada in the years ahead.

Proper design, together with thorough consideration of the bridge's overall behaviour, is critical to ensure optimal performance of the link slab. A faulty design may cause failure of the link slab and, more importantly, may cause structural damage to other components of the bridge.

Based on NYSDOT's experience to-date, UHPC link slabs are performing very well, and with no visible cracks.

REFERENCES

[1] Milton, J., 'Best Practices in Deck Joint Replacement', Virginia Concrete Conference, March 8, 2013.

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[3] Matteo, A., 'VDOT's Use of Concrete Closure Pours to Eliminate Bridge Deck Expansion Joints', Concrete Bridge View Newsletter, Issue 79, Sept/Oct 2015, http://www.concretebridgeviews.com/i79/Article1.php