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An investigation of AASHTO's requirements for providing continuity in simple span bridges made continuous

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ABSTRACT

AASHTO's requirements for providing continuity in simple span bridges made continuous are investigated by performing a parametric study which consists of 140 time dependent analyses for various precast concrete beam shapes. The beam shapes considered include three precast concrete bulb tees (PCBT), two AASHTO type beams, and two Florida I-beams (FIB). Various beam spacing and span configurations are considered. A sectional analysis approach that employs the age adjusted effective modulus method for capturing creep effects is presented for calculating restraint moments. AASHTO models for creep and shrinkage are used to conduct the parametric study. For each case considered a minimum girder age for when continuity can be established is recommended such that the total restraint moment at the intermediate support is equal to or smaller than zero. The recommended minimum girder ages at continuity vary from 55 to 90 days for PCBTs, 55–70 days for AASHTO type beams, and 55–80 days for FIBs. The influence of f'_{ci}, choice of creep and shrinkage model, and choice of analysis method on the magnitude of restraint moments is investigated. The specification of a higher f'_{ci} is an effective technique to reduce the minimum required girder age at continuity. The magnitude of restraint moments appears to be highly sensitive to the selected creep and shrinkage model. The proposed analysis method addresses the shortcomings of other closed form formulations and results in restraint moments that are more sensitive to the girder age at continuity.

1. Introduction

The advantages of creating continuity in bridges composed of precast beams have been embraced by the engineering community in the United States since the 1960s [1,2]. Continuous bridges provide redundancy for overload conditions and extreme events such as vehicular impact, blasts, storm surges or an earthquake. Additionally, the continuity improves rideability and increases the durability of the bridge by eliminating joints at beam ends. It also increases the structural efficiency of the bridge superstructure by making possible longer spans and greater beam spacing. Accordingly, it is essential to ensure that precast beam bridges designed as continuous for live loads do indeed behave as intended. AASHTO LRFD Specifications [3], require that such continuous bridges be designed for restraint moments developed due to time dependent effects or other deformations. These restraint moments could be caused by creep, shrinkage, temperature gradients and support settlements (Fig. 1). The restraint moments can be positive or negative and are typically computed at interior supports of continuous bridges, albeit they affect the design moments at all locations along the bridge. The magnitude and direction of the restraint moments depend on the beam age at the time continuity is established, properties of the beam and deck concrete, and bridge and beam geometry [4].

The commentary of AASHTO LRFD Specifications [3] Article C15.14.1.4.2 states that the data show that the later the continuity is formed, the lower the predicted values of positive restraint moment. Accordingly, it is considered beneficial to wait as long as possible after the beams are cast to establish continuity and cast the deck. Although an early age of continuity can lead to positive restraint moments that may cause cracking at the bottom of continuity diaphragm and affect the efficiency of the continuity at the interior supports, a late age of continuity will maximize negative restraint moments due to differential shrinkage, which could cause transverse cracking on the top of the deck. However, since data form various projects [5,6] do not show the effects of differential shrinkage, it is questionable whether negative moments due to differential shrinkage form to the extent predicted by analysis [3]. Newhouse et al. [7] compared measured restraint moments developed during the early ages of continuity to predicted values obtained using a computer program RMCalc [8,9], and concluded that

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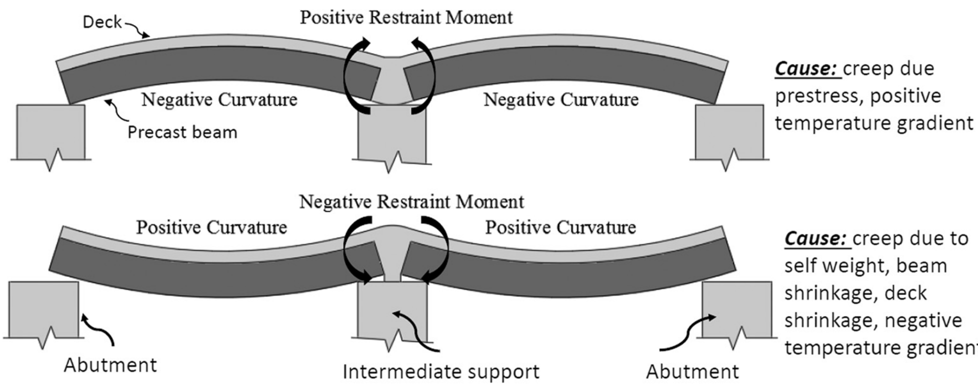

Fig. 1. Development of positive and negative restraint moment in simple span bridges made continuous for live loads.

the measured negative restraint moments were significantly lower than predicted by the program. One of the reasons for such a difference was attributed to the expansion of the deck during curing which creates a positive restraint moment and reduces the negative restraint moment created by differential shrinkage.

As a result, it is the positive restraint moments that typically raise a concern regarding the assumed continuity for live loads. The top of the deck over the interior supports is designed to crack when subject to negative moments from live loads. Differential shrinkage and negative temperature gradients will cause additional transverse cracks on the top of the deck, however, these cracks do not create as big of a concern as those that take place at the bottom of continuity diaphragm due to positive restraint moments because the latter may affect the assumption made about live load continuity.

The current design procedure in AASHTO LRFD Specifications Article 5.14.1.4.5 [3] states that a continuity diaphragm is considered to be fully effective if either of the following is satisfied:

- The calculated stress at the bottom of the continuity diaphragm for the combination of superimposed permanent loads, settlement, creep, shrinkage, 50 percent live load and temperature gradient, if applicable, is compressive.
- The contract documents require that the age of the precast beams shall be at least 90 days when continuity is established and the design simplifications of Article 5.14.1.4.4 are used.

As a result, AASHTO LRFD Specifications [3] allow the designers not to compute restraint moments if the contract documents require a minimum beam age of at least 90 days when continuity is established. If beams are 90 days or older when continuity is established, the creep and shrinkage models provided in AASHTO predict that approximately 60% of the creep and 70% of the shrinkage in the beams, has already occurred prior to establishing continuity [3]. In this case, restraint moments caused by the combination of beam creep and shrinkage and deck slab shrinkage may be taken to be zero. To account for the possibility that even after 90 days some positive restraint moment may develop at the connection and that some cracking may occur, it is required that a positive moment connection be provided with a factored resistance, φM_n, not less than 1.2 M_{cr}. Research by Miller et al. [5] has shown that if the connection is designed with a capacity of 1.2 M_{cr}, the connection can tolerate this cracking without appreciable loss of continuity. This option provides a simplified approach for designing precast beam bridges made continuous and eliminates the need to evaluate restraint moments [3].

If continuity is established at a beam age earlier than 90 days then AASHTO LRFD Specifications [3] Article 5.14.1.4.5 (first bullet) requires that for the connection between the precast beam ends and the continuity diaphragm to be considered fully effective, the calculated stress at the bottom of the continuity diaphragm for the combination of superimposed permanent loads, settlement, creep, shrinkage, 50 percent live load and temperature gradient, is compressive. While Article 5.14.1.4.4 allows the utilization of shrinkage and superimposed permanent loads when establishing whether the stress at the bottom of the continuity diaphragm is compressive, Article 5.14.1.4.2 also states that restraint moments shall not be included in any combination when the effect of restraint moment is to reduce the total moment. However, the commentary of Article 5.14.1.4.5 explains that tests have shown that the connections can tolerate some positive moment cracking and remain continuous [5]. Therefore if the conditions of the first bullet are satisfied, it is reasonable to design the member as continuous for the entire load placed on the structure after continuity is established [3].

Koch [10] analyzed several bridges constructed with PCBTs with the purpose of determining the minimum number of days that the beams had to be stored to satisfy AASHTO's [3] requirements. The PCA Method [11] was used in theses analyses with the updated AASHTO LRFD creep, shrinkage, and prestress loss models. Stresses at the cross-sectional level computed using the PCA method were compared with those using a more accurate sectional analysis method. It was concluded that the PCA Method resulted in time dependent stresses that were higher than those calculated using the more refined sectional analysis method. Also, because the PCA Method allows the utilization of only one creep coefficient to represent the creep in the beam and deck, the results were fairly accurate when the beam and the deck creep coefficients were the same, or similar. Koch [10] concluded that when the negative restraint moments caused by time dependent effects are considered, 67 days was the longest period that a PCBT had to be stored to satisfy AASHTO [3] requirements for the cases analyzed. When negative restraint moments due to time dependent effects were ignored half of the cases considered had to be stored for longer than 90 days. Also, the analyses showed that there was a decrease in the minimum number of storage days when the beam compressive strength was increased from 41.4 MPa to 55 MPa and when the beam spacing decreased from the widest spacing to the closest spacing.

The 90 day continuity provision specified in AASHTO [3] applies to all precast beam bridges made continuous for live loads, regardless of cross-sectional shape, beam depth, span length, concrete creep properties or solar radiation zone. Because in many cases it is more economical to store beams for fewer days, it is important to know the minimum number of days that beams must be stored to satisfy AASHTO's [3] requirements.

The purpose of the research presented in this paper is to revisit the 90 day continuity provision for solar radiation zone 3 for several cross-sectional shapes, beam depths and span lengths and to recommend a modified minimum beam age for when continuity can be established for each considered case. This study also investigates, the influence of initial beam compressive strength (f'_{ci}), selected creep and shrinkage model, and selected time dependent analysis method on the magnitude of restraint moments.