THE DIFFERENTIAL SHRINKAGE DISPLACEMENTS OF BOX SECTIONS PRESTRESSED CONCRETE BRIDGES

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ABSTRACT

In this study, long terms deflections because of the differential shrinkages of box cross section were determined for seven prestressed concrete bridges. In these box girder bridges, the top slab typically has a uniform or nearly uniform thickness of about 250mm, while the bottom slab thickness can vary from about 250mm at midspan to 1.5m at the support. For a concrete slab, the rate of drying is roughly inversely proportional to the square of its thickness. The maximum deflection because of the differential shrinkage was obtained as a 0.257m for Gülburnu Bridge.

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ABSTRACT

In this study, long terms deflections because of the differential shrinkages of box cross section were determined for seven prestressed concrete bridges. In these box girder bridges, the top slab typically has a uniform or nearly uniform thickness of about 250mm, while the bottom slab thickness can vary from about 250mm at midspan to 1.5m at the support. For a concrete slab, the rate of drying is roughly inversely proportional to the square of its thickness. The maximum deflection because of the differential shrinkage was obtained as a 0.257m for Gulburnu Bridge.

Introduction

Prestressed box girder concrete bridges exhibit small deflections during the first years of service and then continue to deflect at a much faster rate. This sudden acceleration of deflection may induce excessive bending moments, overstressing the bridge, and possibly causing damages. To predict long-term deflections correctly, the drying must be realistically reflected in the creep and shrinkage prediction.

Generally, in these box girder bridges, top slab uniform thickness of about 250mm, while the bottom slab thickness can vary from about 250mm to 1.5m (or greater). The variation in thickness between top and bottom slabs of the box cross-section causes large difference in shrinkage of each slab. This differential shrinkage on the slabs may induce additional deflection or internal stress on the members based on the restraint conditions. Recent studies have found the shrinkage is correlated inversely proportionally to the square of its thickness Analysis methods for prestressed concrete box girder bridges are usually assuming the shrinkage strain and creep coefficients are uniform over the entire cross section of the box girder. The objective of this paper is to show that this can result in severely incorrect predictions of long-term deflections, especially when the initial deflections are extrapolated to later points in time.

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Shrinkage Effects

The drying box girder segment, incompatibility of the free shrinkage strains induced in the individual parts by drying produces a self-equilibrating distribution of axial stress. Because these stresses produce creep, they must be taken into account. Although the plane cross sections assumption is not valid for a free standing box girder segment, its use is justified because we are interested in the behavior of the box segment as an element within a long box girder.

It's helpful to give short equations for calculation. A cantilever of length L, drying in a constant environment, and consisting of an box beam and two flanges of different thicknesses d_1 and d_2, uniform over the individual segment lengths (Fig.1). In this calculation the effect of different thicknesses on the moment of inertia of each flange cross section to be ignored. According to Model B3 [1, 2], the shrinkage strains in the top and bottom flanges at drying duration t are

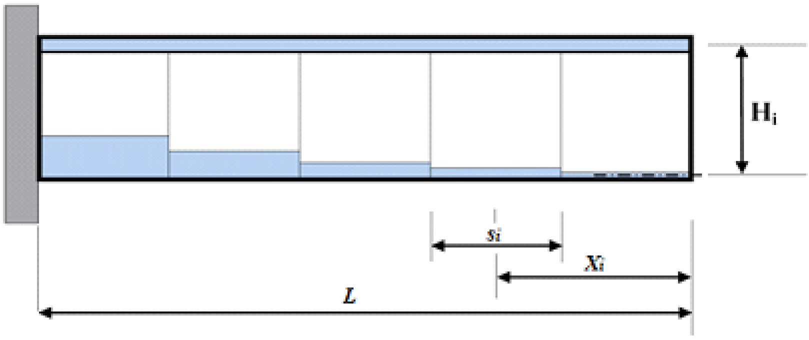

Figure 1. Cantilever with different bottom flange thickness.

$$\varepsilon_1 = \varepsilon_\infty \tanh\sqrt{t/\tau_1} \text{ and } \varepsilon_2 = \varepsilon_\infty \tanh\sqrt{t/\tau_2} \quad (1)$$

where ε_∞ is a constant, and τ_1 and τ_2 are the drying half-times of the flanges [3]. According to diffusion theory,

$$\tau_1 = Cd_1^2 \text{ and } \tau_2 = Cd_2^2 \quad (2)$$

where C is a constant. The shrinkage produces positive curvature of a segment

$$K = (\varepsilon_1 - \varepsilon_2)/H_i \quad (3)$$

in which H_i is the box depth (Fig.1). The contribution of the i-th segment to deflection of the cantilever end due to differential shrinkage is

$$\Delta\delta_i = K_i\, s_i\, x_i \quad (4)$$

in which s_i is the length of the i-th segment, and x_i is the distance of its center from the cantilever free end (i=1,2,....N). Thus, the deflection of the cantilever end due to differential shrinkage can be obtained as a sum of the contributions of individual segments;

$$\delta = \Sigma K_i\, s_i\, x_i \quad (5)$$

Because, for a large bridge, d_1^2/d_2^2 may be as large as 30, it is clear that the ε_1 reaches its final value of 1 well before the ε_2 becomes significant. After that, ε_2 grows in magnitude, causing the upward shrinkage deflection to decrease. The deflection history due to differential shrinkage is, of course, superposed on the creep deflection history.

If the bottom slab is thicker, its shrinkage lags compared to the top flange is slower. Even if both the top and bottom slabs have the same thickness but different widths or surface conditions, a minor lag appears because of a difference in the volume-surface ratio. Consequently, a positive curvature initially develops that would cause upward deflections at the end of a cantilever. If the bottom slab is much thicker, the upward deflection can be large and continue for many years. A maximum upward deflection eventually occurs when shrinkage of the thin top slab nears completion and shrinkage of the thicker bottom slab begins. After that, differential shrinkage causes negative curvature and downward deflections. If the bottom slab is very thick, significant down ward deflection of the box girder occurs at much later time than would commonly be expected.

Drying with simultaneously under the axial force shrinkage effects will cause more deflections. Because it dries faster, the top slab initially creeps faster than the bottom slab, and the centroid of the transformed cross section corresponding to the effective modulus for creep moves downward. Therefore, an axial force applied at the original centroid produces an additional bending moment that slightly increases the initial upward curvature due to shrinkage. Similar to shrinkage, the effect of creep under axial force is eventually reversed. For a thick bottom slab, this occurs only after many years. The shift of the centroid of the transformed cross section also changes the lever arms of prestressing tendons. The combined effect, including drying will increase the deflection. This results a slight increase in curvature due to axial force.

Box Girder Segmental Bridges

Properties of long span box girder sections mostly in Turkey were given in Table1. In this table construction year of bridges were given in parenthesis.The differential shrinkage characteristic in a clamped box girder is also very similar to the case for an internal span of multispan continuous bridges.

Table 1. Properties of box sections prestressed concrete bridges.

Bridge	**Half length of main span (m)**	**Thickness of**		**d_2^2/d_1^2**	**Structural type**
		Top flange at span d_1 (m)	**Bottom flange at support d_2 (m)**		
Palau (1977-1996)	120.5	0.28	1.10	15.4	Cantilever
Kömürhan (1986)	67.5	0.30	0.65	4.7	Cantilever
İmrahor (1998)	57	0.25	1.00	16	Continuous
Gülburnu (2009)	82.5	0.25	1.40	31.4	Continuous
Beylerderesi (2011)	95	0.25	0.95	14.4	Continuous

Table 1. Properties of box sections prestressed concrete bridges(cont'd).

Bridge	**Half length of main span (m)**	**Thickness of**		d_2^2/d_1^2	**Structural type**
		Top flange at span d_1 (m)	**Bottom flange at support d_2 (m)**		
Akarsın (2012)	66	0.25	1.00	16	Continuous
Tigem (2013)	36	0.25	0.50	4	Continuous

Some information about the long span prestressed concrete were given as follows,

Koror-Babeldaob Bridge in Palau

The bridge at time of the finish in 1977, it was the prestressed concrete box girder cantilever bridge with the longest span in the World. The Koror-Babeldaob (KB) Bridge was connecting Koror, Babeldaob islands. Unfortunately the failure of the Koror-Babeldaob Bridge in Palau, Fig.2, occurred on 26 September 1996, at around 5.45 afternoons [4-6]. The layout of bridge is shown in Fig.2the main span was 240.8m long. The side spans, which had been chosen, were 53.65m long. From the end piers cantilevers of 18.6m extended towards the abutments. So the overall structure was 385.28m long.

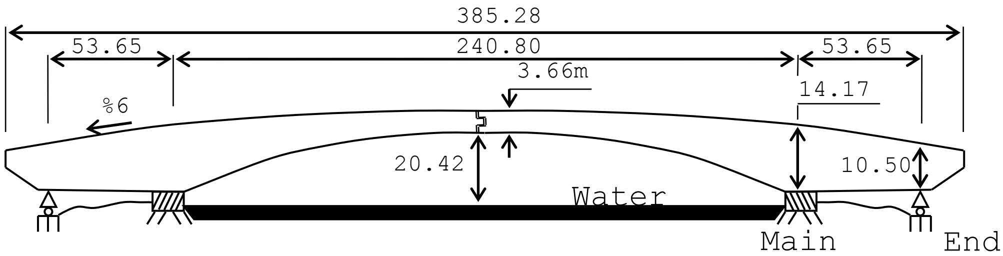

Figure 2. Elevation of bridge geometry

Maximum deflection occurs at the age of concrete was 20000 days as a 0.254m as shown in Fig.3.

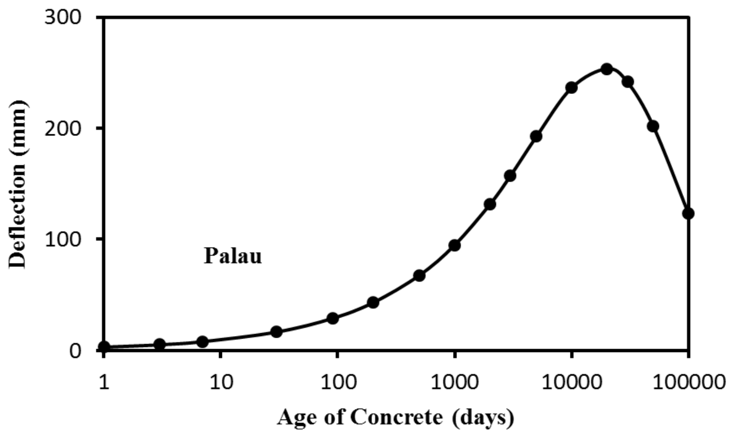

Figure 3. Deflection of the free end of the cantilever due to shrinkage of Palau Bridge

Kömürhan Bridge

Kömürhan Bridge at time of the finish in 1986, it was the prestressed concrete box girder cantilever bridge with the longest span in the Elazığ (Turkey). In Fig.4 deflection of cantilever end of bridge was given with age of concrete [7].

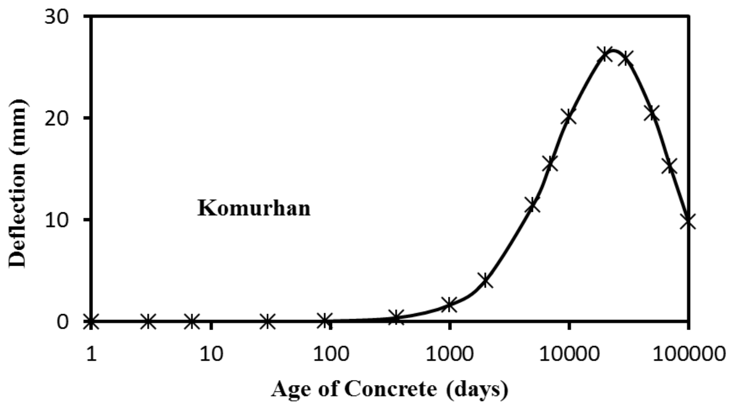

Figure 4. Deflection of the free end of the cantilever due to shrinkage of Komurhan Bridge.

İmrahor Bridge

The bridge was the prestressed concrete box girder continuous bridge with the symmetrically 5 spans, constructed on 1996, in the Ankara (Turkey). The deflection of mid point of main span of continuous İmrahor Bridge was given in Fig.5.

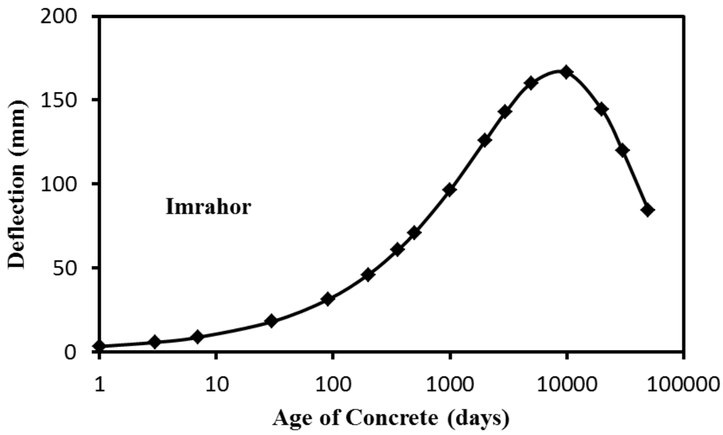

Figure 5. Deflection of the free end of the cantilever due to shrinkage of İmrahor Bridge

Gülburnu Bridge

The bridge was the prestressed concrete box girder continuous bridge with the asymmetrically 3 spans, constructed on 2009, in the Giresun (Turkey). Deflection of mid point of main span of continuous bridge was given in Fig.6.

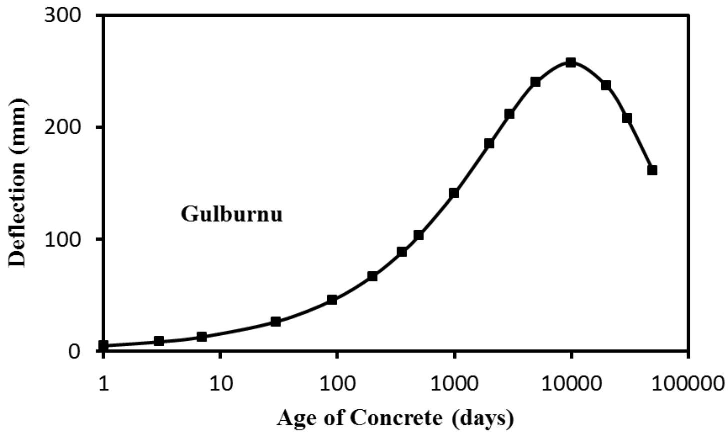

Figure 6. Deflection of the free end of the cantilever due to shrinkage of Gülburnu Bridge

Beylerderesi Bridge

The bridge was the prestressed concrete box girder continuous bridge with the asymmetrically 3 spans, constructed on 2011, in the Malatya. Longest span bridge in the Turkey. Deflection-Age of concrete curve was given in Fig.7.

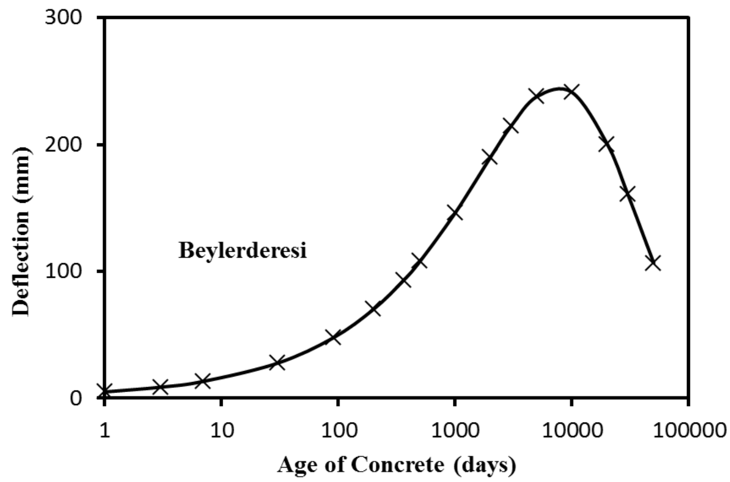

Figure 7. Deflection of the free end of the cantilever due to shrinkage of Beylerderesi Bridge

Akarsın Bridge

The bridge was the prestressed concrete box girder continuous bridge with the symetrically 3 spans, constructed on 2012, in the Artvin (Turkey). Deflection of mid center of main span was given in Fig.8.

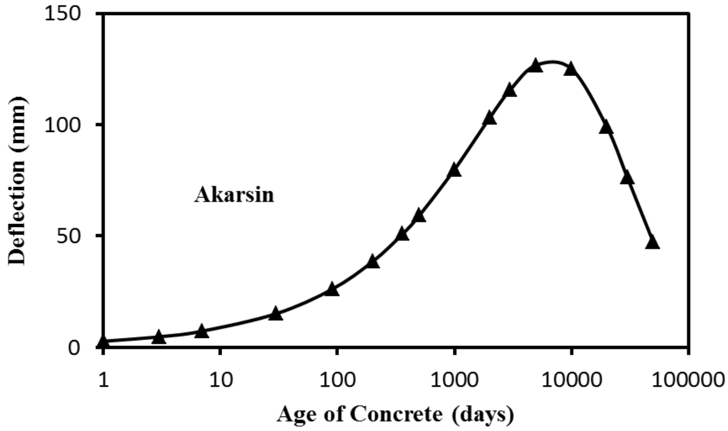

Figure 8. Deflection of the free end of the cantilever due to shrinkage of Akarsın Bridge

Tigem Bridge

Tigem Bridge [8] was the prestressed concrete box girder continuous bridge with the symetrically 5 spans, constructed on 2013, in the Ankara (Turkey). Deflection of mid point of main span of 5 span continuous Tigem Bridge was given in Fig.9.

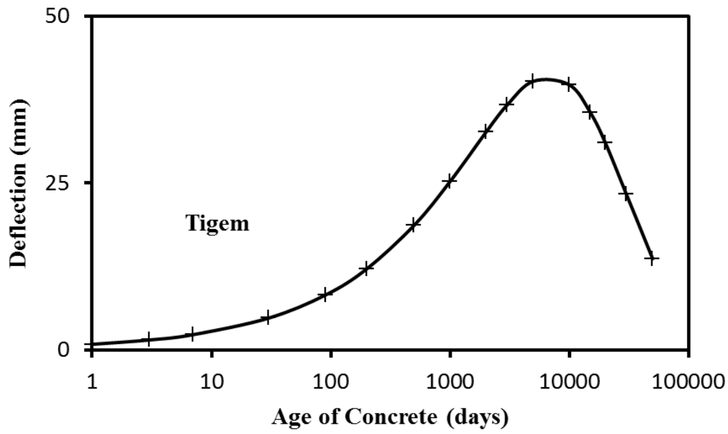

Figure 9. Deflection of the free end of the cantilever due to shrinkage of Tigem Bridge

Comparisons of Different Box Girder Bridges

As shown in Fig.10 deflection curves of different segmental bridges initially go up. However once the thinner top slab has dried out and stopped shrinking, the slower shrinkage of thicker bottom slab increases, causing large downward deflections.

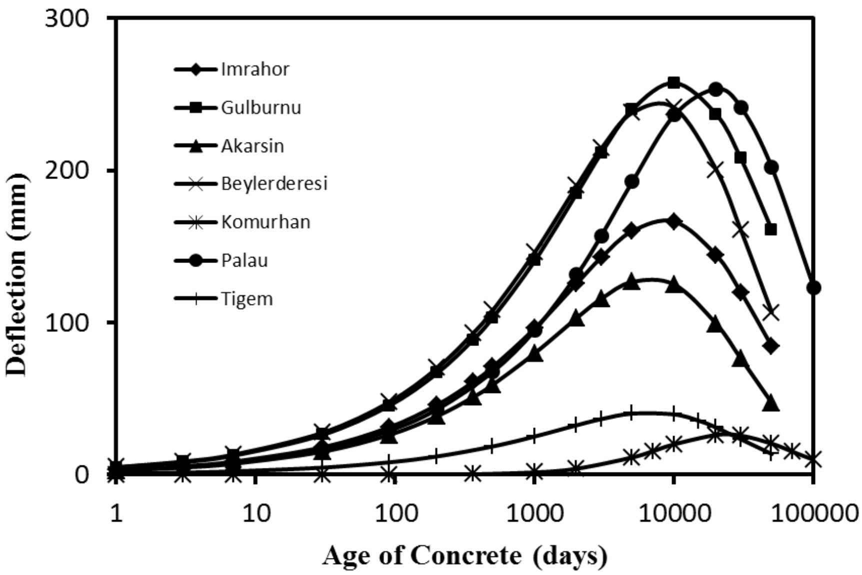

Figure 10. Comparisons of deflection of the free end of the cantilever of different box girder bridges

Conclusions

Prestressed box girder bridges typically exhibit small deflections during the first years of service and then continue to deflect excessively. The cause is primarily a large difference in shrinkage between the top and bottom slabs of the box cross-section and, to a small degree, a difference in drying creep. This difference is explained by a large difference between the top and bottom slab thicknesses and the proportionality of drying and shrinkage rates to the square of the thickness.

The biggest differential shrinkage displacement of box sections prestressed concrete bridges was calculated for Gülburnu Bridge as a 0.257m at the time of 10000days.

Different bridges give different maximum at a different time.

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