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CAST-IN-PLACE POST-TENSIONED CONTINUOUS BRIDGES IN TURKEY: APPLICATION AND ADVANTAGES

Ö. Özkul[1], and J. E. Erdoğan[2]

ABSTRACT

The majority of bridges in Turkey are constructed of single-span precast girders. These girders are usually prefabricated at a nearby precast plant, transported to site and placed over bearings on piers. This technique has proven to be uneconomical and unaesthetic as seen in many applications. The span length is usually limited by lifting capacity or transportation constraints. These restrictions limit the span of single span girders to about 30-40m, with depths around 1.4-2.0m. Maximum moment due to the applied loads is created at mid-span with support section bearing zero moment, leading to an inefficient section. In addition, massive piers heads at every 30-40m are required, with two-lines of bearings at each pier. The resulting isostatic structure is uneconomical, and with deep girders/frequent bulky piers unaesthetic to a tending eye.

On the other hand, hyper-static continuous girder bridges share the full static moment over supports and mid-span. Continuity over supports can be achieved by post tensioning the multi span girders after the concrete is cast. A span length of around 50m is not very uncommon in this technique. Section depths may be variable, deeper at supports and 1-1.4m mid-span, resulting in economical placement of material where it's needed most. Less frequent piers with single line of bearings is required. Economical and aesthetic structures are created using the post-tensioning technology. In addition, speed of construction is quite comparable as witnessed in Ankara Fen Lisesi Bridge: 2 bridges side by side with 31m+51m+31m spans were completed in about 60days.

Although many precast single span girder bridges exist in Turkey, the knowledge and application of post-tensioning to continuous bridges is limited. Few recent examples to this technique are discussed in this paper. Fen Lisesi Bridge in Ankara, Haliç Metro Access Bridge in Istanbul, and Bridges at Ataturk Airport in Istanbul are presented in brief as case studies.

[1]Technical Coordinator, Freysaş-Freyssinet, Istanbul, Turkey
[2]General Manager, Freysaş-Freyssinet, Istanbul, Turkey

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ABSTRACT

The majority of bridges in Turkey are constructed of single-span precast girders. These girders are usually prefabricated at a nearby precast plant, transported to site and placed over bearings on piers. This technique has proven to be uneconomical and unaesthetic as seen in many applications. The span length is usually limited by lifting capacity or transportation constraints. These restrictions limit the span of single span girders to about 30-40m, with depths around 1.4-2.0m. Maximum moment due to the applied loads is created at mid-span with support section bearing zero moment, leading to an inefficient section. In addition, massive piers heads at every 30-40m are required, with two-lines of bearings at each pier. The resulting isostatic structure is uneconomical, and with deep girders/frequent bulky piers unaesthetic to a tending eye. On the other hand, hyper-static continuous girder bridges share the full static moment over supports and mid-span. Continuity over supports can be achieved by post tensioning the multi span girders after the concrete is cast. A span length of around 50m is not very uncommon in this technique. Section depths may be variable, deeper at supports and 1-1.4m mid-span, resulting in economical placement of material where it's needed most. Less frequent piers with single line of bearings is required. Economical and aesthetic structures are created using the post-tensioning technology. In addition, speed of construction is quite comparable as witnessed in Ankara Fen Lisesi Bridge: 2 bridges side by side with 31m+51m+31m spans were completed in about 60days.Although many precast single span girder bridges exist in Turkey, the knowledge and application of post-tensioning to continuous bridges is limited. Few recent examples to this technique are discussed in this paper. Fen Lisesi Bridge in Istanbul, Haliç Metro Access Bridge in Istanbul, and Bridges at Ataturk Airport in Istanbul are presented in brief as case studies.

Introduction

The single span precast girder bridges are the most common type built in Turkey. Although popular, span length of these bridges is limited by lifting capacity or transportation constraints. With limited span length, frequent placement of piers is required. This affects the total cost of construction especially if piling is needed. 30-40m span lengths with 1.4-2.0m section depths are quite common in pre-tensioned precast girder construction.

Due to isostatic nature of these bridges, maximum bending moment is created at the midspan section, with support sections bearing no moment. This demonstrates inefficient use of material, as the support section is not utilized. However, if continuity is achieved through post-tensioning, the total static moment ($w\ l^2/8$) is shared both by midspan and support sections.

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Continuity over supports can be achieved by post-tensioning. Depending on the design and site conditions, post-tensioning can be performed in stages or after the whole structure is cast. Providing continuity also eliminates the use of expansion joints and reduces the number of bearings at each pier.

This paper presents the main differences between pre-tensioned precast girders and cast-in-place post-tensioned continuous bridges. A brief discussion summarizing the pros and cons of both methods is provided. Few recent examples to this technique are discussed in brief as case studies.

Comparison of the Two Techniques

Figure 1 shows moment diagram of a single-span beam and a continuous girder. The maximum moment in a single-span girder is calculated at midspan. Sizing the section at maximum moment location for ultimate loads and checking for serviceability is generally adequate for the design. Whereas, in a continuous girder, the bending moment is carried by both the midspan and the support sections. The absolute value of moment at any section would be less than the moment in a simply-supported single girder. This helps the designer to size shallower sections with the same span, or span longer distances with the same depth.

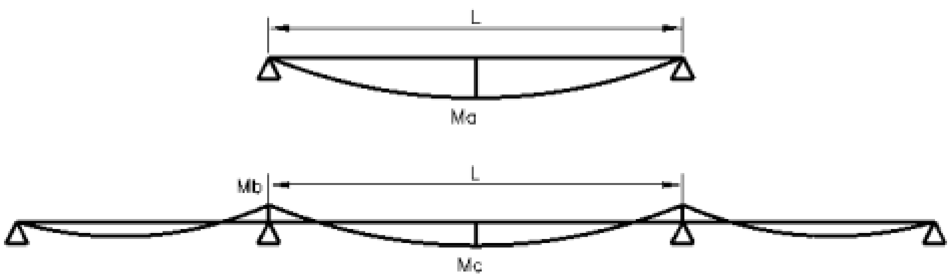

Figure 1. Moment diagram of a simply supported and continuous girder.

When post-tensioning is used, tendons in the section can be placed in either with a drape or as a straight line. Draping tendons is not very common in pre-tensioned precast members as massive deviators may be required. Usually straight bonded pre-tensioned strands are used in precast girders. Since the moment diagram reduces towards the ends of a simply-supported single girder, capacity provided by the straight strands is not needed at these locations. Generally, ends of precast pre-tensioned members are debonded to limit uplift and cracking at the member top surface.

On the other hand, it is much easier to place draped ducts in cast-in-place concrete girder. Strands may be installed in ducts before or after the concrete is cast. Instead of draping, the tendons may be installed straight and the concrete section can be tapered, creating a variable section depth. In continuous systems, generally the support moments and shear are higher than the midspan moments and shear. Therefore, at supports, deeper sections are provided as compared to the midspan sections. By doing so, the material is placed where it’s needed most, utilizing an efficient economical design.

Figure 2 shows a typical variable cross–section bridge. Generally, the middle 60% of the span length is constructed of a constant cross–section. Depending on the depth of the constant portion, hollow pipes can be left in concrete to reduce its self–weight. The sections on the remaining 20% of the span on each side are deepened to provide the required capacity.

Providing continuity and variable cross–section reduces the concrete quantity in the range of 30%, as will be demonstrated with an example in the following sections.

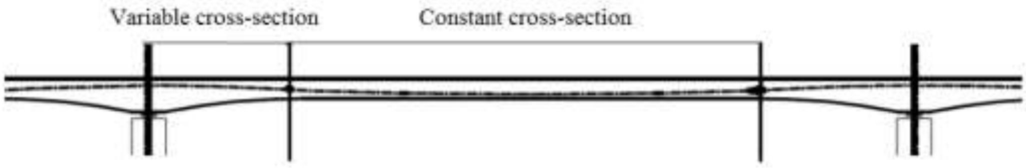

Figure 2. Variable and constant cross-section.

Figure 3 shows the span lengths of a simply-supported and continuous girder system. The middle pier can be removed, and the length of the central span can be increased by providing continuity and variable cross-sections.

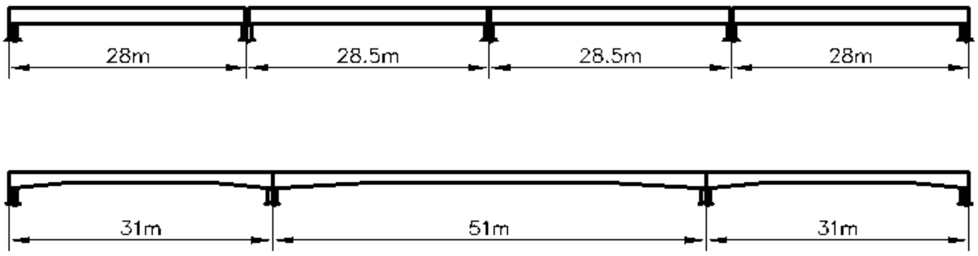

Figure 3. Span length comparison of simply supported and continuous systems.

In precast simply-supported single-span girders, two lines of bearings and a single line of expansion joint is needed at each pier (Figure 4). Providing two lines of bearings may increase the width of the pier cap in longitudinal direction. Due to the continuity at piers, post-tensioned continuous bridges would need single line of bearings, which could minimize the pier cap size (Figure 4). Moreover, expansion joints at bridges require constant maintenance and repair. Providing few number of expansion joints would result in less maintenance and saving on the required repair works.

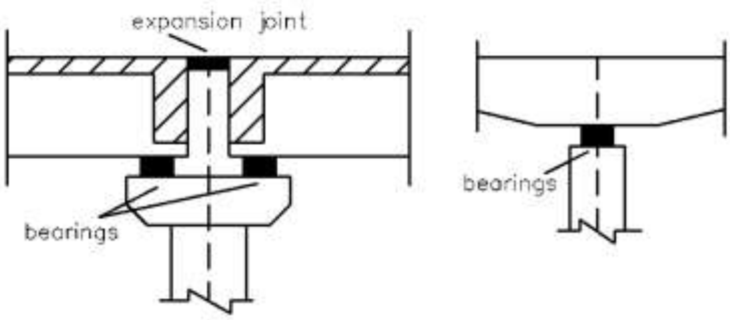

Figure 4. Detail at pier: Precast girder and Continuous post-tensioned girder.

Since pre-tensioned precast girders are cast as straight members, providing curves in plan becomes quite complex. The curve has to be broken down to as few straight segments as possible to form the curvature. Independent of the maximum possible span length, at intersection of each straight segment a pier has to be provided as a support. However, in cast-in-place continuous post-tensioned concrete decks, curvatures in plan can easily be formed, with minimum number of piers. One recent example is the curved bridge at Ataturk Airport in Istanbul shown in Figure 5.

Figure 5. Continuous post-tensioned variable–depth curved bridge at Ataturk Airport.

Numerical Example

Kayabaşı Viaduct in Istabul is chosen to compare the two methods, considering the same span length. This study was done during the preliminary design stage. The total length of the viaduct is 240m. The deck width is 33.9m, with 2x3m sidewalks, 2x10.5m roadways and a light rail train line of 1x6.9m in the central section (Figure 6).

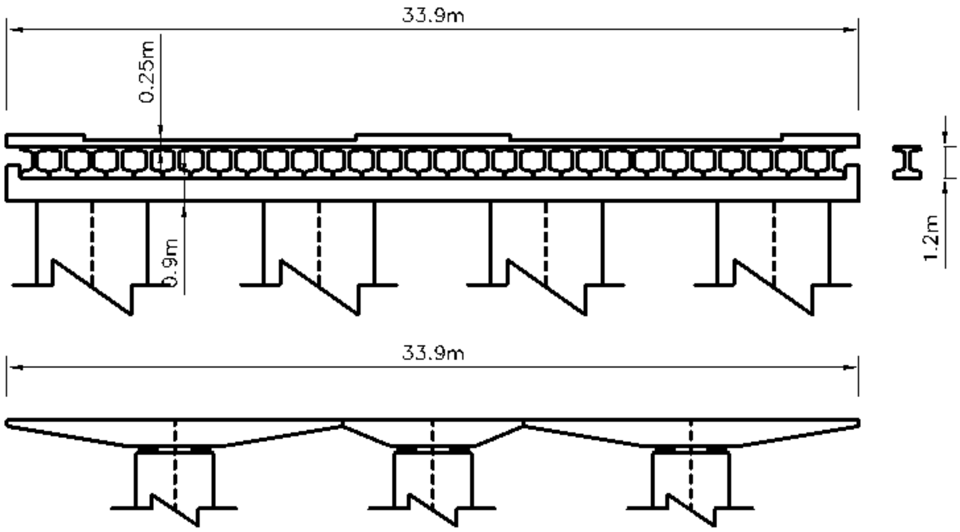

Figure 6. Kayabaşı Viaduct: Pre-tensioned Precast and Post-tensioned alternative.

Pre-tensioned Precast Girder Option

The pre-tensioned precast girder option has 29.2m long simply-supported spans (Figure 6). The depth of the cast-in-place topping deck concrete is 25cm, and the depth of the pier head beam is 90cm. Pre-tensioned precast girders are 120cm deep placed side by side. With the deck concrete, total depth of the viaduct becomes 145cm at midspan.

Considering the precast girders, deck concrete and pier head beam, the average concrete thickness is calculated as 85cm. The total concrete volume (excluding piers) is estimated as

33.9m x 0.85m x 240m=6,915 cubic meters.

With 30m spans on average and 4 piers at every support, 28 piers are needed. Pier cross-section area for this option is 5.9 square meters. The total concrete volume for piers is computed as 28 x 7.33m x 5.9 sqm=1,211 cubic meters. Total concrete volume for this option results to 8,126 cubic meters and summarized in Table 1.

Post-tensioned Continuous Deck, Variable Solid–Section Option

For a matching comparison, spans lengths are kept the same as the pre-tensioned precast option, at 30m. Three separate continuous variable section decks are designed for this option, two for the roadway, and one in the middle for the light rail train. The details are shown in Figure 8. For 30m continuous spans, at midspan 75cm thick and at support 100cm thick solid concrete sections are required. The sections are tapered towards the edges. Since designed as continuous deck, pier head beams are not required in this option.

The average concrete thickness is calculated as 66cm. The total concrete volume (excluding piers) is estimated as 33.9m x 0.66m x 240m=5,370 cubic meters.

With reduced weight of the deck, 3 piers at every support are needed (21 piers). The pier cross-section area for this option is also reduced to 3.3 square meters. The total concrete volume for piers is computed as 21 x 7.33m x 3.3 sqm=508 cubic meters. Total concrete volume for this option results to 5,878 cubic meters and summarized in Table 1.

Table 1. Comparison between pre-tensioned and post-tensioned alternatives.

		Pre-tensioned Precast	Post-tensioned Continuous	Difference	
				Quantity	%
Depth at midspan	(cm)	145	75	–70	–48%
Depth at support	(cm)	235	100	–135	–57%
# of piers		28	21	–7	–25%
Foundation reaction at piers	(tons)	20,315	14,695	–5,620	–28%
Total concrete volume	m^3	8,126	5,878	–2,248	–28%
Total reinforcement	(tons)	1,011	721	–290	–29%

As this numerical example demonstrates, compared to the pre-tensioned precast girder option with the same span length, the post-tensioned continuous deck option creates 30% reduction in material and self-weight. Reduction in material quantities results in direct cost savings, whereas reductions in self-weight results in savings in the foundation design and required number and size of bearings. Moreover, due to the continuity of the deck, few number of expansion joints are needed, which reduces the initial cost, and long term maintenance costs of the bridge.

In addition to the savings in construction cost and time, the resulting structure is aesthetically pleasing with its slender deck, and provides a comfortable drive with no joints.

Cast-in-Place Post Tensioned Continuous Bridges in Turkey

The following section summarizes the recent projects completed in Turkey.

Fen Lisesi Bridge in Ankara

Two bridges side by side, each with two lanes and sidewalks crossing the Konya Highway over an underpass is constructed at the Fen Lisesi junction in Ankara. The design was performed by KMG Proje, construction works were undertaken by Enam İnşaat, and the post-tensioning operations, as well as pot bearing and expansion joint supply, were performed by Freysaş-Freyssinet for the Ankara Metropolitan Municipality. The bridges are designed as three-span continuous, with 31m side spans and 51m main span, crossing 113m total length. Variable solid cross–section deck, 2.8m deep at supports and 1.4m at midspan is provided. In order to reduce the concrete weight, hollow pipe sections are left in the midspan sections of the bridge along the bridge length (Figure 8). From inception to finish, two bridges are completed in less than 60 days.

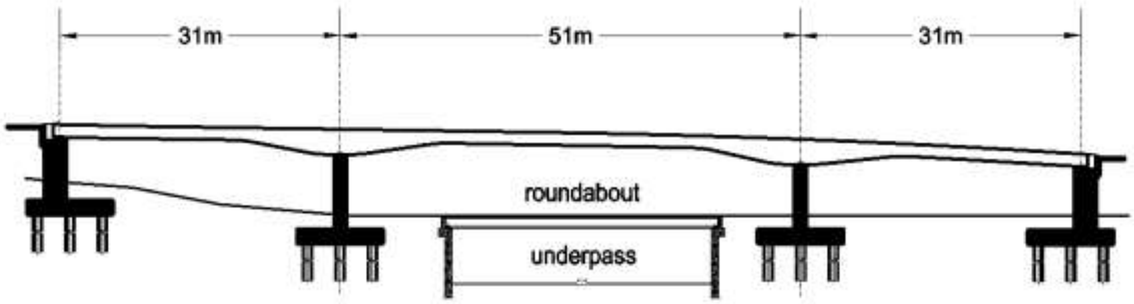

Figure 7. Ankara Fen Lisesi Bridge – elevation

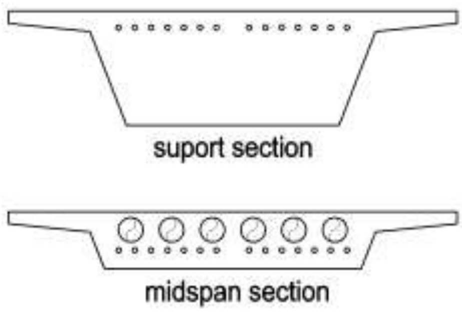

Figure 8. Variable cross-section at support and midspan (with voids).

Figure 9. View of the Konya Highway underpass – bridge under construction.
(picture credit: Ankara Metropolitan Municipality)

Figure 10. Completed Bridge.

Haliç Metro Access Bridge in Istanbul

The approach viaducts of the Haliç Metro Bridge provide access to the cable-stayed structure crossing over the Haliç, also known as Golden Horn. The owner is Istanbul Metropolitan Municipality, the contactor is Astaldi-Gülermak JV, and Freysaş-Freyssinet was in charge of supply and installation of post-tensioning, expansion joints and seismic bearings. Two viaducts, named south-west (SW) and north-east (NE) are constructed on the north and south of the crossing. The SW approach consists of 5 continuous spans (total length 170m) and the NE approach consists of 7 continuous spans (total length 240m) with 44m and 45m main span lengths, respectively (Figure 11 and 12). Variable solid cross–section deck, 2.2m and 2.5m deep at supports and 1.1m at midspans is provided in SW and NE viaducts, respectively.

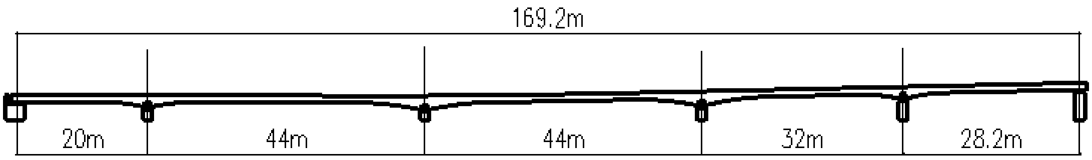

Figure 11. South-west approach viaduct at Haliç Metro Access Bridge.

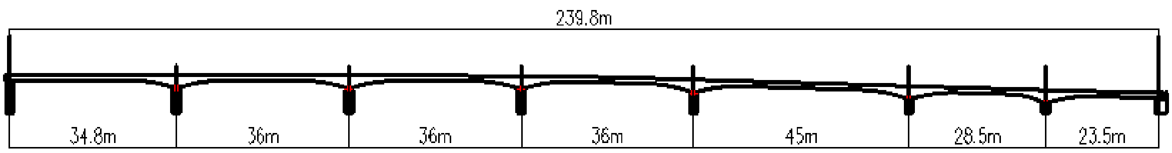

Figure 12. North-east approach viaduct at Haliç Metro Access Bridge.

Figure 13. Haliç Metro Access Bridge.

Bridges at Ataturk Airport in Istanbul

The overpass at the Atatürk Airport in Istanbul consists of 7 post-tensioned bridges in total (Figure 14). 4 of the 7 are single span post-tensioned curved (in plan) bridges. The longest of the single-span curved deck bridges spans 46m, with 2.0m depth at support and 1.2m depth at midspan sections. Remaining 3 bridges are multi-span, curved in plan continuous decks. The longest of these 3 bridges crosses a total length of 168m with 30m side spans and 36m main spans (4 piers). The required depth at support sections is 1.76m and at midspan sections 1.06m. All 7 bridges were completed in about 9 months. The owner is Istanbul Metropolitan Municipality, the contactor is Özka İnşaat, and Freysaş-Freyssinet was in charge of supply and installation of post-tensioning and seismic bearings.

Figure 14. Bridges at Ataturk Airport in Istanbul.

Figure 15. Curved tendon ducts being installed (Ataturk Airport-Istanbul).

Figure 16. Underside of completed bridge (Ataturk Airport-Istanbul).

Conclusions

This paper summarizes the benefits of continuous post-tensioned concrete deck bridges as opposed to pre-tensioned precast alternatives. A numerical example, comparing quantities for same span lengths is provided. It is shown that the post-tensioned continuous deck option creates 30% savings in material quantities and weight. The reduction in weight also reduces the loads for foundation design and the required number of bearings. The one piece integral deck eliminates the number of expansion joints to a few, reducing maintenance costs and providing increased drive comfort. Curvature in plan can easily be provided with minimum number of piers. Apart from the benefits in economy, an aesthetically pleasing slender thin deck is formed. Few recent examples to this technique in Turkey are discussed.

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