The Design and Construction of Kemaliye Bridge

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Abstract The design of Kemaliye Bridge, with a total length of 290.0 m and width of 17.0 m, has been carried out by Emay International Engineering and Consultancy Inc. Within the scope of the Project entitled "Design and Engineering Services for Kemaliye and Kozlupınar Bridges located on Kemaliye-Dutluca Road", implemented by the client Turkish Republic, Ministry of Transport, Maritime and Communication General Directorate of Highways, 16.Division Directorate of Highways. Kemaliye Bridge has 3 spans with 140.0 m. central span length and side spans each of 75.0m length. As measured from the top level of foundations, the pier heights are 60.0m each. The bridge deck has been designed as prestressed post-tensioned concrete by cantilever method. The segment lengths are 3.0m, 4.0m, and 5.0m. The depth of the box girder deck varies between 8.50m on piers and 3.50m at midspan.

During the design stage of the Kemaliye Bridge, which will be constructed by the balanced cantilever method, deflections and calculations involving time dependent factors such as creep and shrinkage have been carried out following the completion of each segment. Furthermore, losses in cable prestressing forces due to various factors (creep, shrinkage, elastic loss, relaxation, friction, anchor set) and also stresses and deformations due to uniform temperature differences (thermal gradient) have been taken into account in the calculations.

The environmental effects of the construction of the bridge has been minimized by virtue of the balanced cantilever method of construction, and following the completion of the construction work and aesthetic and elegant structure will emerge which will be harmonious with the environmental scenery and attractions.

1 Introduction

From the past up to the present, bridges have been important engineering structures which span over difficult geographical obstacles and topographical conditions such as rivers and deep valleys and thus ensure a continuous transportation. Nowadays, by virtue of technological advances and improvements in the quality of structural quality, using prestressed post-tensioned concrete, the number of bridges built by balanced cantilever method of construction which are suitable for spanning over difficult terrain such as rivers and deep valleys in particular, were increased considerably. The Kemaliye Bridge planned to be constructed over the Euphrates River is one example of such bridges which are to be built by using the balanced cantilever method. Upon the completion of the project, Iliç and Kemaliye districts of Erzincan province will be connected directly to Arapgir district of Malatya province (Figure 1). Due to the nature of construction method, the environmental effects of bridge construction by balanced-cantilever method will be a minimum; following the construction period the bridge will appear to be an esthetic and slender structure, being harmonious with the natural surroundings blending well with the natural scenery.

Kemaliye Bridge which is to be built within the scope of the “Design and Engineering Services for Kemaliye and Kozlupınar Bridges located on Kemaliye-Dutluca Road” implemented by the client, “Turkish Republic Ministry of Transportation General Directorate of Highways 16. Division Directorate of Highways”, has a total length of 290m and width of 17m. It has been designed by Emay International Engineering and Consultancy Inc. In this paper, the design criteria, methods of analysis including the construction stage and the results obtained concerning the Kemaliye Bridge to be constructed by the balanced-cantilever method, has been evaluated.

Figure 1 Location of Kemaliye Bridge

2 Balanced Cantilever Method

The balanced cantilever method of construction is preferred for bridges spanning over deep valleys where large span lengths are required. This method of construction is most suitable an economical for spans between 60m and 200m; for such a span length range, this method is 20% more economical as compared to other construction methods. From the consideration of cost, precast segments and cast in situ box section concrete segments are suitable for span length ranges of 60-110m, and 110-200m respectively; the segments are too heavy in the latter range for precast construction. Depending on the weights, the segment length vary between 3-6m. The box girder deck depth is variable.

In this method, the initial segments are constructed over the completed piers. Following the completion of the pier foundation, the pier column is constructed by climbing form, starting from foundation top up to the underside of the deck structure. Upon the completion of the pier (column) the assembly of the joint segment which is monolithic with the pier concrete is started. The concrete is cast in three stages, namely the bottom, web and top sections. Following the geometrical checks the reinforcing steel is placed. After placing the reinforcing steel at the required position, the ducts for the tendons are located within the formwork, in accordance with the number of tendons required as shown in the drawings. Afterwards starting from the each pier segment one extra segment is assembled at each side of the pier segment, applying the same procedure, maintaining the "balance". After the completion of a pair of segment, another pair is added in a similar fashion until the advancing segments physically join at the centre of span. At each segment, when the concrete compressive strength reach the value required, the tendons are located inside the ducts previously installed at their required position are tensioned at each segment end. The concrete at final segments at abutments is cast by diaphragm formwork system. Finally, the bridge box girder deck construction is completed by completing the key segments at midspan.

3 Technical Information Concerning the Bridge

Kemaliye Bridge has three spans with a main span length of 140m, and each side span of 75m, total length is 290m (Figure 2, 3). The bridge is designed to be built by the balanced cantilever method. By using prestressed post-tensioned cast in place concrete; the bridge deck has a box section type of cross-section.

Figure 2 General Plan View of the Bridge

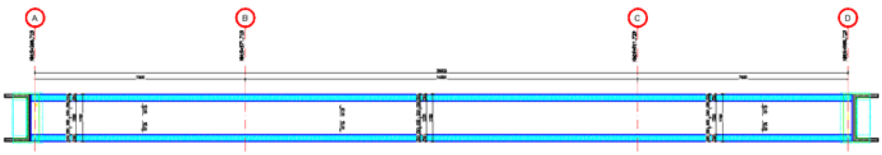
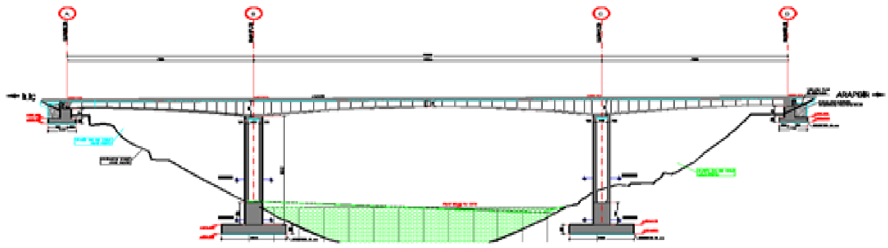
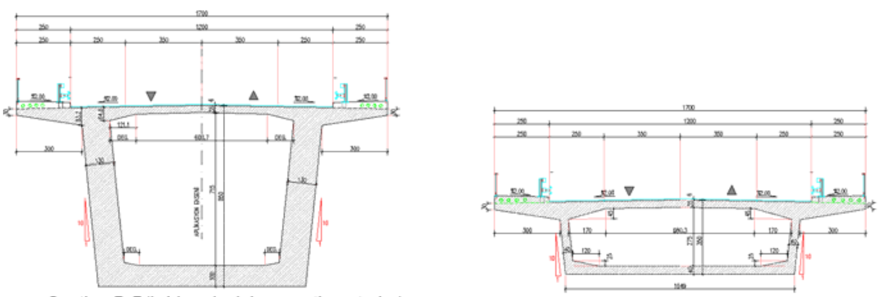


Figure 3 Longitudinal Section of the Bridge



The depth of the box girder deck was necessarily selected to be variable, taken as 8.5m at pier section and 3.5m at mispan(Figure 4). The pier segment which is monolithic with the pier top, 8.0m long. Apart from the key segments at mid-main span and abutment segment, there are 14 intermediate segments at each side of a pier, namely 2x1x3m+2x3x4m+2x10x5 in order from the pier towards the midspan (main span) and/or abutment. The abutment segment and the midspan key segment has lengths of 7.5m and 2m respectively. The joint 3m(at the abutment side) of the 7.5m long abutment segment has a solid section. The pot bearings have been designed as guided sliding type, allowing movement in the bridge longitudinal direction and fixed in transverse direction of the bridge. There are four pot bearings at each abutment. The vertical and horizantal load carrying capacity of each pot bearing is 19917 kN and 1950 kN respectively. At each abutment two shear keys were designed so as to counteract the horizantal forces. The pier cross section is solid with dimensions of 9.488m x 7m for 12m meaured from the foundation top, and the rest being hollow(box section) measuring 9.488 x 7m, with wall thickness of 1.3m. The bridge pier and abutment foundation were determined to be shallow foundation type in accordance with the Geotechnical Report. The pier footing measures 26m x 28m with a 5m thickness and abutment footing measures 11.3m x 18m with 2.5m thickness.

Figure 4 Typical Bridge Cross Section (at pier and at midspan)



Section B-B(bridge deck box section at pier) Section C-C(bridge deck box section at midspan)

4 Materials

The quality of the materials used in the load bearing deck and substructure members are given as follows:

Concrete

Prestressed post-tensioned box girder deck : C50 (f_{ck} = 50 MPa)
Pier columns : C40 (f_{ck} = 40 MPa)
Other reinforced concrete members : C35 (f_{ck} = 35 MPa)
Levelling and infill concrete : C16 (f_{ck} = 16 MPa)

Reinforcement

All substructure pier columns and deck : B500C (fyk = 500 MPa)

Structural Steel

At Shear Key : S355JR (fy=355 Mpa)

Posttensioning Strands

Type of strand: Low Relaxation ASTM A416/A416M-2 Grade1860 [270]
Tensile Strength (f_{pu}) : 1860MPa
Yield Strength (f_y) : (0.9 f_{pu}) = 1674 MPa
Cross Section Area : 150 mm^2/strand
Post-tensioning tendons : 19C15 (Freysinnet-C Range)

5 Design Criteria

- The dimensioning, load assumptions, load combinations, construction stages and design checks pertaining to balanced cantilever bridge members have been performed in accordance with AASHTO LRFD 2012 Specifications.
- Seismic design spectrum used in the calculation of the earthquake forces acting on the bridge has been determined by using “Technical Guidelines for the Developments in Bridge Engineering Design and Construction in Turkiye” Table K.E.K.7.1.1 prepared by the General Directorate of Highways.
- “Design Guide Prestressed Concrete Bridges Built Using the Cantilever Method” prepared by the Ministry of Transport and Infrastructure of France has been made use of during the bridge design stage.
- Truck loadings indicated in ASSHTO LRFD Specification has been adopted for live load calculations on bridge deck.
- Stresses occurring at bridge deck concrete and post-tensioning tendons has been checked in accordance with stress limits indicated in AASHTO LRFD Specification, both for construction stage and for service stage.

6 Loads

The loads used in calculations are presented herewith:

Dead Loads:

Reinforced concrete and prestressed concrete structural members : γ_b = 25 kN/m^3

Asphaltic coating, levelling : γ_k = 23 kN/m^3

Sidewalk (pavement) weight (25 cm thickness): 31.25 kN/m

Railing weight (guard rail+pedestrian railing): 3.00 kN/m

Asphalt layer weight (6 cm thickness): 23.46 kN/m

Live Loads:

HL-93 Design Truck Load, Design Lane Load and Design Tandem Vehicle Load as shown in AASHTO LRFD 2012 Specification has been used as live load on the bridge. Live loads are defined on particular lanes in Midas Civil analysis model, and thereby the most unfavourable forces and moments encountered in the system have been evaluated.

Wind Loads:

Wind loads acting on the structure have been calculated in accordance with AASHTO LRFD 2012 Specification Section 3.8; in the calculation of wind load acting on the structure itself and on live loading a wind speed of 180.246 km/h has been taken (AASHTO LRFD 3.8.1.1-1).

Wind loads on structures (horizontal): 3.0 kN/m^2

Wind loads on structures (vertical): 0.96kN/m

Wind loads on vehicles: 1.45kN/m^2

Temperature Effects:

Temperature effects on the structure has been considered to act Uniform Temperature and Temperature Gradient in accordance with AASHTO LRFD 2012 Specification Section 3.12.2 and 3.12.3. uniform temperature effect has been taken into account at Midas Civil Model as between +20^{0}C and -25^{0}C according to cold climate category. As for temperature gradient effect the map of radiation regions in Turkiye, temperature table T_i in the “Technical Guidelines for Developments in Bridge Engineering Design and Construction in Turkiye” Section K.1.17 has been used. As Kemaliye district is located in Zone 1, temperature values were obtained as T_1=28^{0}C and T_2=6^{0}C.

Effects of Creep and Shrinkage (SR, SH)

The effects of creep and shrinkage has been taken into consideration in accordance with the clauses of “CEB-FIB 1990 Model Code” by defining material properties in the model as a result of which such effects have been calculated automatically by the program. As the deck cross sectional area is variable, there is no fixed section ratio dependent on creep. Creep coefficients were derived from the relevant equations in accordance with the specification. Approximately creep and shrinkage values corresponding to a 30 year period were taken into account in calculations.

Earthquake Loading (EQ)

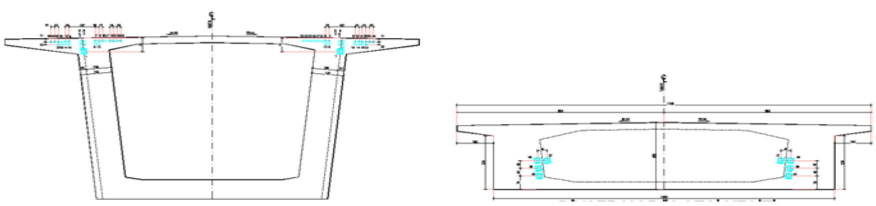
The seismic loads acting on the bridge has been taken into account by using multi mode spectral analysis method in accordance with AASHTO LRFD Table 4.7.4.3.1-1 “seismic design”. The design seismic spectrum has been derived from “Technical Guidelines from Developments in Bridge Engineering Design and Construction in Turkiye”, Table K.EK.7.1.1. In the Guidelines, values of S_s= 0.9686 and S_1=0.7203 were given for Kemaliye Bridge. The soil category has been taken as class B on bridge soil. In order to establish the design acceleration spectrum, the necessary values of T_0 and T_s were found to be T_0=0.149s and T_s=0.744s respectively for local soil class B.

7 Structural Analysis and Design

During the structural modelling stage, general purpose structural analysis program such as Midas Civil and SAP2000 computer programs have been used. The bridge abutments and prior foundation were modelled in SAP2000 program. Other members and structural units in the system were modelled in Midas Civil Program. In the Midas Civil Program, a 2-dimensional structural model was established and an analysis was performed, taken into account the construction stage, creep and shrinkage effects in concrete and relaxation of post-tensioning tendons. The cross-section of the post-tensioning tendons extending in the bridge longitudinal direction has been determined by taking dead loads and live loads into account. In the preliminary tendon calculation the procedure was as follow: for cantilever tendons the maximum cantilever case of construction stage, and for tendons at section bottom service loading (all dead and live loads) condition was considered.

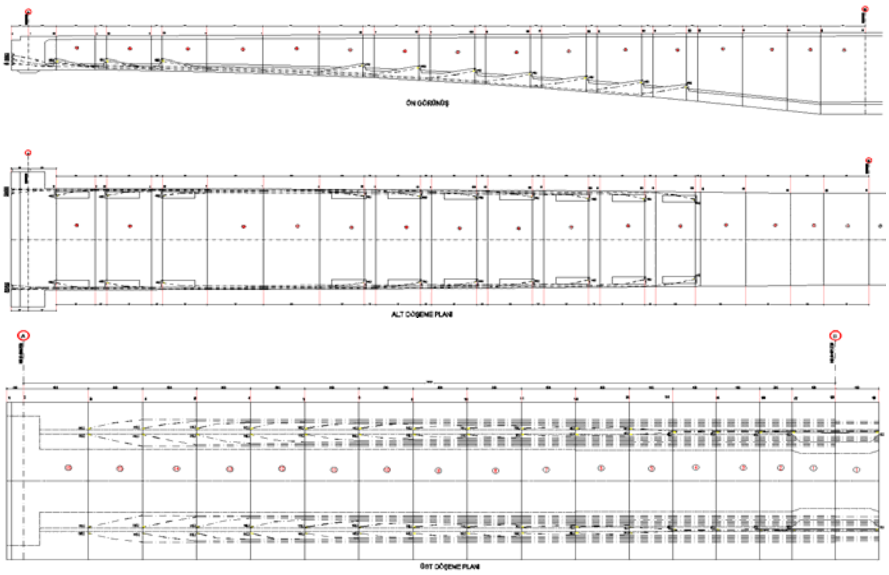
Typical cross-sections showing the positions of post-tensioning tendons in the section, is shown in Figure 5.

Figure 5. The Layout of Post-tensioning Tendons (Cross Section)



The post-tensioning tendons so determined were defined in the model placing them in suitable positions (Figure 6) and as a result of the analysis, concrete stresses and deformations in the deck sections were checked. Transverse post-tensioning tendons had to be used since the width of the bridge is 17m. These tendons also were defined in Midas Civil Program.

Figure 6 The Layout of Post-tensioning Tendons



8 Construction Stage Analysis

The construction stage analysis of the bridge was done by using Midas Civil Program, which enabled the checking of stresses and displacements derived from sections and which took into consideration the time dependent effects. The construction stages defined in the calculation model were as follows:

1- Firstly, the column pier and the pier segment is constructed.

2- Subsequently both adjacent segments are constructed simultaneously (symmetrical construction).

It was assumed that a period of 12 days would be required for all the work in each segment, which was defined in the program;

1. Day: Removal of the traveller forms and their assembly for the next segment
2. Day: Positioning and placing the steel reinforcement and tendon ducts
3. Day: Concrete casting

4.~ 6. Days: Curing of concrete

7. Day: Tensioning the post-tensioning tendons

3- Abutment connection work, following the completion of all segments.

4- Continuity tendons at side spans are tensioned.

5- Construction of key segment at main span.

6- Continuity tendons at main spans are tensioned.

7- After the completion of the construction stage analysis, the structure is aged to 30 years and 100 years in order to take into account the time dependent effects of material such as creep and shrinkage.

9 Analysis Results

Prestressed concrete box girder deck stresses and post-tensioning tendon stresses derived from the results of service limit state analysis and construction stage analysis performed in relation to computer model, have been compared with the stress limits stated in AASHTO LRFD Specification. Furthermore, reinforced concrete strength design method of calculation was carried out for the deck, pier columns, abutments and foundations according to the dynamic analysis results. But in this paper only the stresses and displacements has been shown.

9.1 Design Checks for the Deck

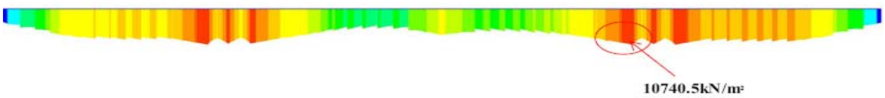
Stresses at prestressed concrete box girder deck due to both construction and service limit state were checked. It was observed that the compressive and tensile stresses at the top and bottom concrete fiber were well within the limiting values (Figure 7). A summary of maximum compressive and tensile stresses are presented in the table below (Table 1).

Table 1 Summary of Maximum Stresses Occurred in the Deck

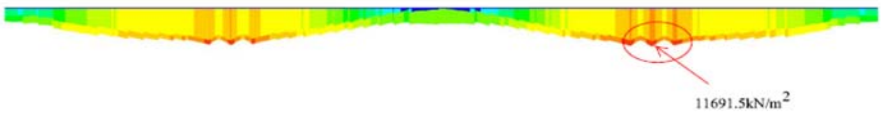
	Compressive Stress		
	Allowable Stress	Maximum Stress	Element No
Construction Stage	22500kN/m^2	10740kN/m^2	50
Service Limit State	30000kN/m^2	11691.5 kN/m^2	53
	Tension Stress		
	Allowable Stress	Maximum Stress	Element No
Construction Stage	3520kN/m^2	1708.88 kN/m^2	52-53
Service Limit State	3520kN/m^2	1727 kN/m^2	52-53

Figure 7 Box Girder Deck Stress Checks

Compressive stress at bottom fiber under construction condition

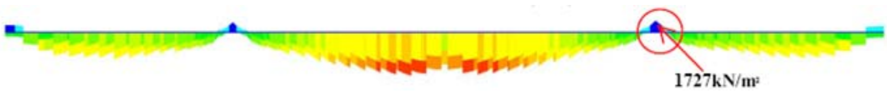


Compressive stress at bottom fiber under service condition



Tensile stress at top fiber under construction condition

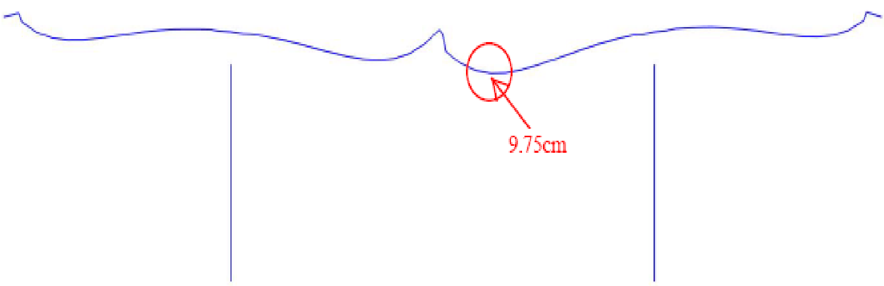
Tensile stress at top fiber under service condition



Furthermore, deck displacement curves for each construction stage have been evaluated and the maximum displacement following a 100 years period was found to be 9.75 cm (Figure 9).

Finally, box girder deck stress values and displacement curves were observed to be within the limiting values stated in AASHTO LRFD Specification.

Figure 8 Maximum displacement curve for deck



Construction stage no.20, displacement curve (36000days–100years)

9.2 Post-tensioning Tendon Checks

It was seen the amount of post-tensioning tendons derived from the analysis performed was sufficient and satisfies the stress limitations. There are 52 tendons at each pier section, 10 tendons under the section at midspan of main span and 7 tendons under the section at midspan of each side span. The number of transverse tendons are placed at 70cm centres varies from segment to segment.

The tendon stresses obtained from the calculation model analysis were checked for stress limit values stated in AASHTO LRFD table 5.9.3.1 the resulting tendon stresses were found to be lower than the limits.

10. Conclusion

Kemaliye Bridge, which is to be built within the scope of the “Design and Engineering Services for Kemaliye and Kozlupınar Bridges located on Kemaliye-Dutluca Road’’ implemented by the client, “Turkish Republic, Ministry of Transportation, General Directorate of Highways, 16. Division Directorate of Highways”. It has been designed by Emay International Engineering and Consultancy Inc. In this paper, the design criteria, methods of analysis including the construction stage and the results obtained concerning the Kemaliye Bridge to be constructed by the balanced-cantilever method, has been evaluated. The environmental effects of the construction of bridge has been minimized by virtue of the balanced cantilever method of construction, and following the completion of the construction work an aesthetic and elegant structure will emerge which will be harmonious with the environmental scenery and attractions.

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