DESIGN OF THE HIGHEST BRIDGE IN TURKEY: A RIGID FRAME BRIDGE

ÇAMLICA BRIDGE

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Abstract As a part of the improvement plan of the existing roadway, Çamlıca Bridge is going to be constructed on Ermenek – Mut State Road, in the vicinity of Ermenek, Turkey. The bridge will be built on a 196 m deep valley to provide an easier and shorter the travel route between two towns.

As a result of the topography of the valley, the bridge is designed as a V-shaped rigid frame bridge with two inclined main piers, consisting of three spans. The bridge has a post-tensioned box girder deck. Main piers and two inclined back piers are monolithically connected to the deck, forming two triangular forms on each side, due to stability considerations. As an extra safety measure, rock anchors are designed under each abutment.

Total bridge length will be 350 meters, consisting of two 80 meters long side spans and the main span of 190 meters. Box girder deck height varies between 4 meters in mid-span and 10 meters over the piers. Side spans will be constructed on temporary supports while the main span is designed to be constructed segmentally as cantilevers from both sides simultaneously, to meet in the middle with by closing segment. Friction pendulum bearings are used under the main piers and pot bearings are used on abutments. Due to its unique geometry and length, the design of Çamlıca Bridge offered several engineering challenges.

When completed, both by means of the total bridge length and the height from valley bottom, Çamlıca Bridge is going to be the longest and the highest rigid frame bridge in Turkey. It will also be among the longest reinforced concrete rigid frame bridges in the world.

1 Introduction

Çamlıca Bridge was planned and designed under the tender of General Directorate of Highways in 2014. The reason for building a bridge on a mountain road with difficult and harsh conditions is to establish a shorter and convenient access between two emerging town of South Turkey.

Figure 01: Slope View - Ermenek Side

The design of Çamlıca Bridge is more like a study of the economics, maintainability and constructability of the passage. The Frame Bridge has total length of 350m. with 80m. + 190m. + 80m. spans. Side spans are executed with falsework; the central span, with progressive cantilevers. At each abutment, two friction pendulum bearings were placed to accommodate rotation, expansion, and contraction of the structure. Çamlıca Bridge is an elegant, slender, 350 m. long, cast-in-place post-tensioned concrete, rigid frame bridge with integral abutments that takes advantage of the massive basalt rock formations at each abutment.

Bridges play an important role in our country's transportation infrastructure. Bridges span rivers, bays, canyons, roads, and railroads; providing critical connections and catalyst for commerce. Inexpensive transportation is essential to building and sustaining a prosperous economy and bridges are one of the primary factors in determining what our transportation costs will be [1].

2 Design Criteria

2.1 Specifications

- General Directorate of Highways, Republic of Turkey, Technical Specifications for Highway Bridges,
- AASHTO, LRFD Bridge Design Specifications
- AASHTO, Standard Specifications

2.2 Materials

Concrete : C40/50 (TS EN 206-1:2002)

f_c' = 40 MPa	; Compressive strength of concrete at 28 days
f_{ci}'= 32 MPa	; Minimum Compressive strength of concrete at Post-tensioning
E_c = 34026 MPa	; Modulus of elasticity

Post-tensioning Tendons: Low-relaxation Steel (ASTM A416)

f_s'	= 1860 MPa	; Tensile Strength
f_{py}	= 1674 MPa	; Yield Strength
E_s	= 196500 MPa	; Modulus of elasticity
μ	= 0.23	; Friction Coefficient
K	= 0.00066	; Wobble Effect Coefficient (for 1 m.)
SL	= 10 mm	; Seating loss
fsi'	= 1395 MPa	; Characteristic value of max. force (0.75 fs')
a	= 15.24 mm (0,6 in.)	; Strand Diameter
A_s	= 1.40 cm^2	; Strand Section Area
#	= 19	; Number of strands at each tendon

Reinforcement Bars : S420 (TS 708:2010)

f_y	= 420 MPa	; Yield strength
E_s	= 203900 MPa	; Modulus of elasticity

2.3 Loads

The loads affecting the Çamlıca Bridge are summarized as follows:

2.3.1 Permanent Loads

Concrete Unit Weight = 24.5 kN/m^3
Unit weight of Pavement = 10.72 kN/m (0,25 m. height)
Unit weight of Guardrail = 3.6 kN/m (Only one guardrail)
Weight of asphalt coating = 1.38 kN/m^2 (6 cm. thickness)

2.3.2 Live Loads

According to “Technical Specification for Highway Bridges”, a publication of General Directorate of Highways, "H30-S24" type concentrated and uniform live load is selected for the bridge.

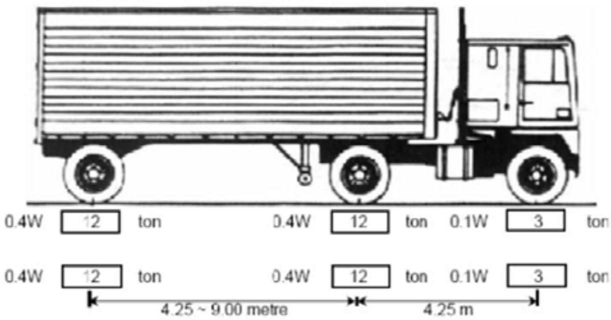


Figure 02: Point load values and their distribution

2.3.3 Wind Loads

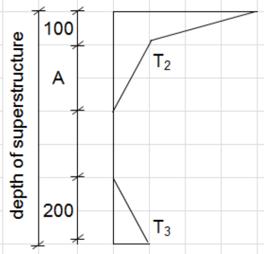
Wind Loading to Superstructure = 2.40 kN/m^2
Wind Loading to Substructure = 1.90 kN/m^2
Wind Loading to Vehicle = 1.50 kN/m

2.3.4 Thermal Effects

Temperature change in Concrete structures = ± 20 ^{o}C (TU)
Thermal Coefficient = 9.90*10^{-6} / ^{o}C
Calculated thermal gradients and stresses are as follows:

T = Thermal Effects

E =	34026000	kN/m^2	α E =	336.9	kN/m^2
α =	9.90E-06	1 / °C			



Positive Thermal Gradient (TG)			Negative Thermal Gradient (TG)		
T_1 =	30.0	°C	T_1 =	-6.0	°C
T_2 =	8.0	°C	T_2 =	-1.6	°C
T_3 =	0.0	°C	T_3 =	0.0	°C
σ_1 =	-10106	kN/m^2	σ_1 =	2021.1	kN/m^2
σ_2 =	-2695	kN/m^2	σ_2 =	538.97	kN/m^2

For heating and cooling Tu supposed to be + 20°C / -20°C .

2.3.5 Creep and Shrinkage

Creep and shrinkage effects will be automatically calculated by the LARSA 4D program, according to the provisions of “CEB-FIP 1990 Model Code". While modeling the structure, nonlinear time-dependent analysis type is used which takes into account construction phases too.

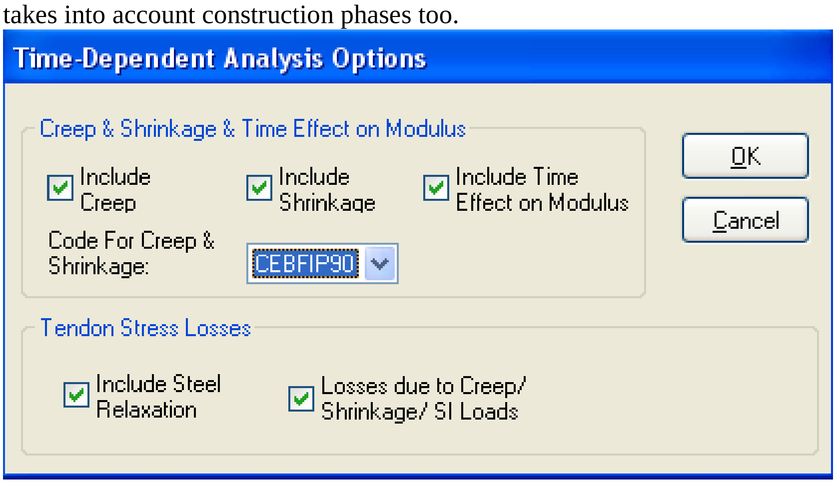


Figure 03: Creep And Shrinkage Load Analysis Parameters

2.3.6 Seismic Loads

C_{sm} : Elastic Seismic Response Coefficient
A : Acceleration Coefficient (A = 0.244) (1000-yr return period)
S : Site Factor, (S = 1.0 ; Type I)
T : Bridge period of vibration

Supports are chosen to be friction pendulum type, which allows damping of seismic forces. Seismic forces reduced by 25% beginning from 2/3 of dominant period.

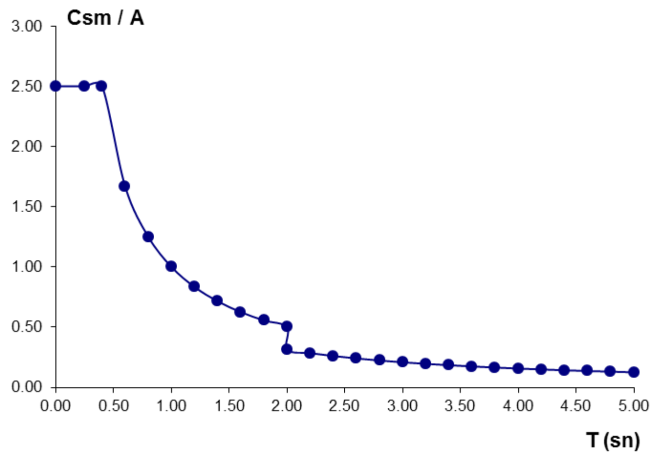


Figure 04: Modified spectrum for 25% damping (FPS)

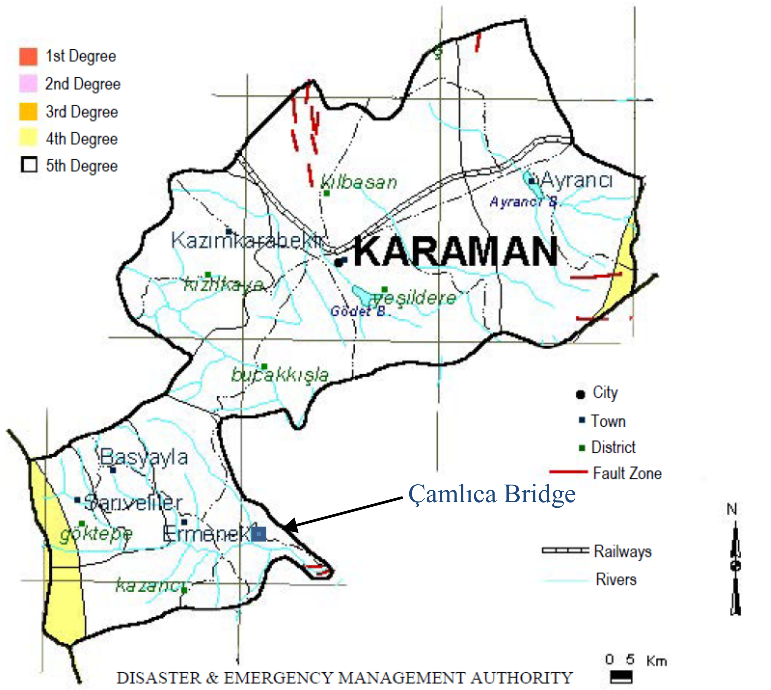


Figure 05: Seismic regions near to site according to seismic hazard map of Turkey

3 Geometry

The superstructure box girder depth varies from 4.00 m. at midspan to 10.00 m. at the pier, with a bottom flange thickness varying from 0,25 m. in the midspan region to 1,20 m. at the pier. The box girder web walls are supporting a deck slab of variable thickness. A variable-depth, single-cell, box-girder cross section with cantilevered deck overhangs provides a 15,00 m. wide bridge deck to accommodate two 3,50 m. wide traffic lanes, two 2,50 m. wide emergency lanes and two 1,50 m. wide sidewalks.

Figure 06: A rendered photo of Çamlıca Bridge and the valley passed over.

The top slab has constant dimensions for the full length of the bridge. Its thickness varies transversely from a minimum of 0,25 m. to a maximum of 0,70 m. at the intersection with the webs. The maximum 0,70 m. depth of the top slab is required to accommodate the cantilever tendons needed for the main span.

Beginning from the west abutment to east in full length, superstructure of the Bridge has a 3.25% slope.

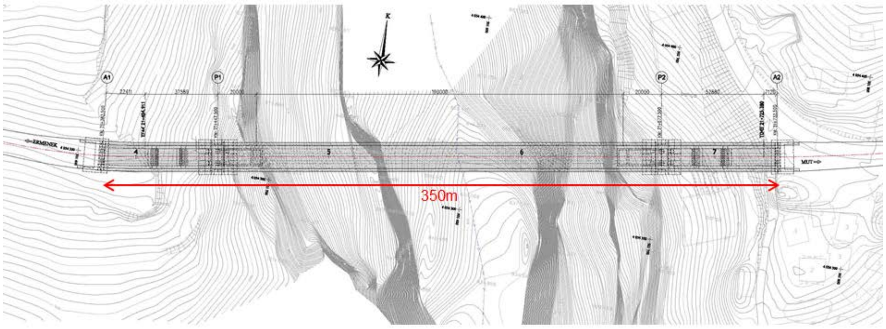


Figure 07: Plan view of Çamlıca Bridge.

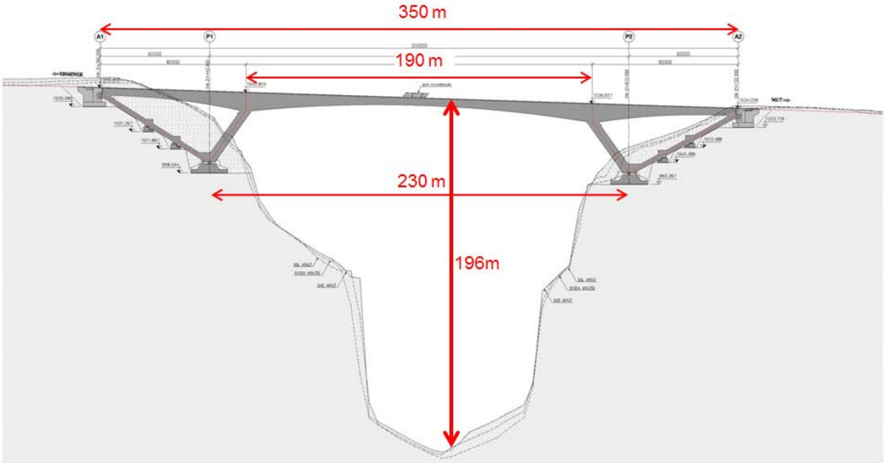


Figure 08: Elevation view of Çamlıca Frame Bridge

The concrete box section is post-tensioned longitudinally and transversely. The longitudinal post-tensioning consists of two sets of tendons. The cantilever tendons, located in the top slab, are stressed during cantilever construction shortly after a new segment is added. The span tendons, located in the bottom slab, are used in the central part of the spans to provide continuity between adjacent cantilevers.Transverse post-tensioning is utilized in the top slab.

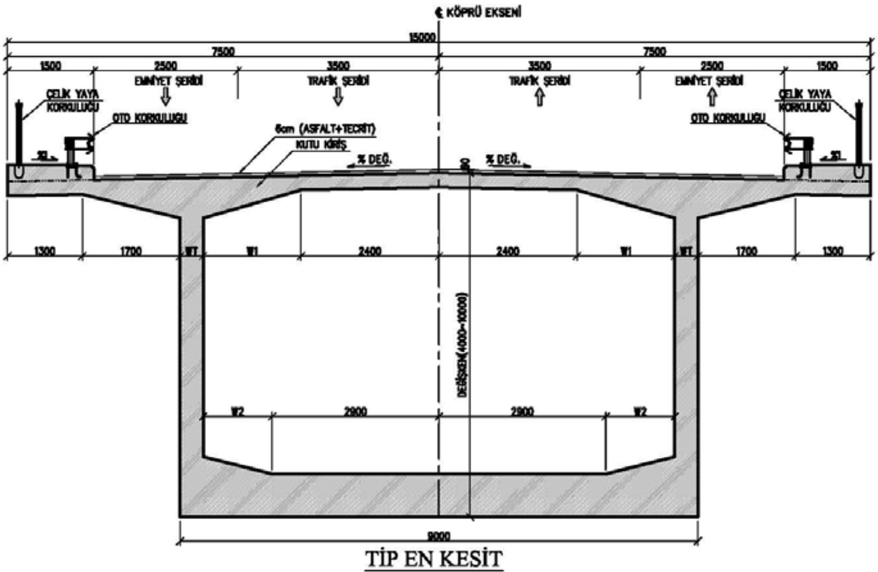


Figure 09: Typical Section of Çamlıca Frame Bridge

4 Analysis and Design

Full 3D finite element models (frame, area and solid element models for nodes) were prepared for the analysis using LARSA 4D program with post tensioning elements in all construction stages accordingly. The structural analysis and the verifications for ultimate limit states, serviceability limit states and fatigue for the bridge as well as for all construction stages are carried out in accordance with the principles set out in AASHTO LRFD Bridge Design Specifications.

In the preliminary design of tendon quantities, minimum number of upper tendons and tendon layouts are determined in the case of maximum cantilever stage. Preliminary design parameters are checked by comparing stress and deflection values with limit values at each segment sections.

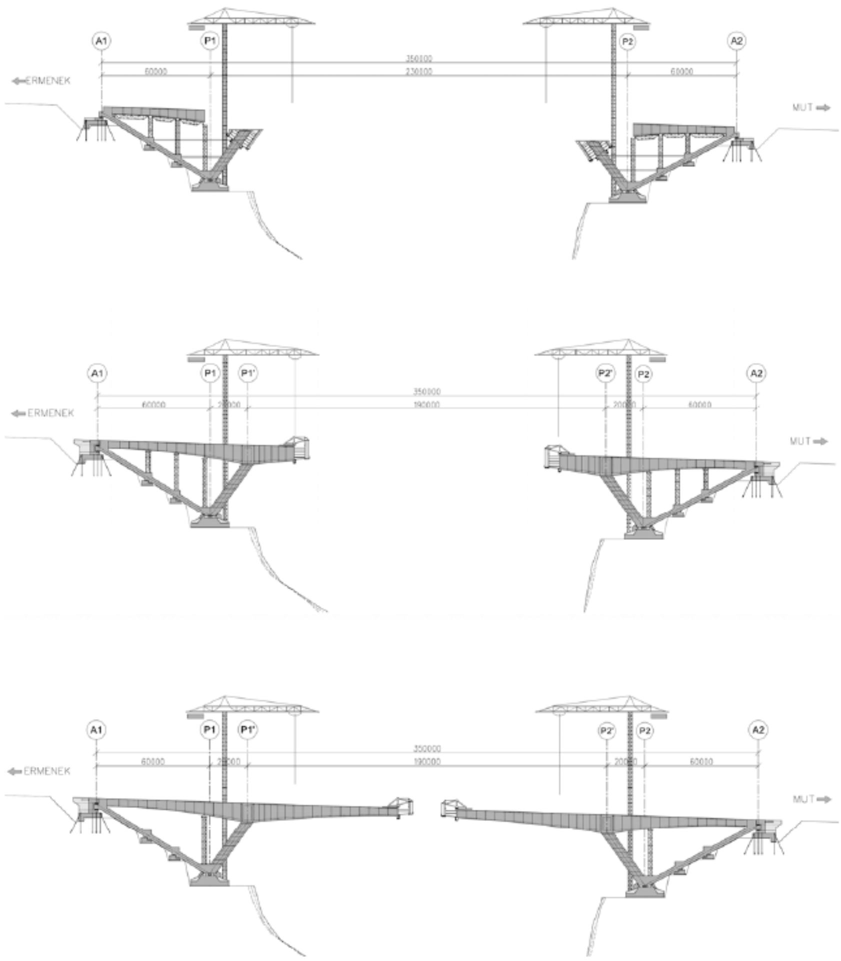


Figure 09: Typical Construction stages of a frame bridge

5 Conclusions

We read and hear quite a lot about "sustainable solutions" as society comes to grips with the ever-increasing demand on infrastructure in the face of dwindling resources. Basically, to achieve sustainable bridges, ecological, economic, and social factors are all have to be considered. Sustainable development is the challenge we face to be good stewards of Country's limited natural resources, energy, transportation, not only for today's needs, but also for the needs of future generations[1].

Bridges are subject to large cyclical loadings, fatigue, extreme temperature fluctuations, rain, snow and ice, deicing chemicals, scour, accidental impacts, and so on. Each and every bridge design is unique because of local site conditions. Today post-tensioned, cast-in-place concrete bridges represent large amount of new bridges built on highways. Despite severe weather conditions, extreme temperature ranges and heavy use of deicing chemicals, concrete bridges are providing increased service life due to improvements in materials and corrosion protection systems.

Building a major bridge over a deep scenic valley is a challenge that most bridge designers would welcome. The first goal was to place a bridge in the scene that, at the least, does not detract from the valley. The more important goal is to place a bridge that actually adds to the site's scenic quality, which becomes an asset to the site, and that fits the site so well that it looks like the bridge has always been there [2]. Construction of Çamlıca Bridge is started in the first quarter of 2016 year. Similar to the design phase, we hope that, Çamlıca Bridge will overcome remaining engineering challenges successfully in construction phase to reach to targeted aesthetic values.

Acknowledgments This document was prepared for the Istanbul Bridge Conference 2016.

6 References

1 Raymond Paul Giroux (2010), Sustainable Bridges, Supplement to Perspective, Aspire Magazine, 2010: web issue
2 Frederick Gottemoeller (2014), Jeremiah Morrow Bridge, Project Section, Aspire Magazine, Winter 2014: p: 15