Computers and Concrete, *Vol. 24, No. 4* (*2019*) *303-311*
DOI: https://doi.org/10.12989/cac.2019.24.4.303

Determination of minimum depth of prestressed concrete I-Girder bridge for different design truck

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(*Received February 18, 2019, Revised August 13, 2019, Accepted August 27, 2019*)

Abstract. The depth of superstructure is the summation of the height of girders and the thickness of the deck floor. In this study, it is aim to determine the maximum span length of girders and minimum depth of the superstructure of prestressed concrete I-girder bridge. For this purpose the superstructure of the bridge with the width of 10m and the thickness of the deck floor of 0.175m, which the girders length was changed by two meter increments between 15m and 35m, was taken into account. Twelve different girders with heights of 60, 75, 90, 100, 110, 120, 130, 140, 150, 160, 170 and 180 cm, which are frequently used in Turkey, were chosen as girder type. The analyses of the superstructure of prestressed concrete I girder bridge was conducted with I-CAD software. In the analyses AASHTO LRFD (2012) conditions were taken into account a great extent. The dead loads of the structural and non-structural elements forming the bridge superstructure, prestressing force, standard truck load, equivalent lane load and pedestrian load were taken into consideration. HL93, design truck of AASHTO and also H30S24 design truck of Turkish Code were selected as vehicular live load. The allowable concrete stress limit, the number of prestressed strands, the number of debonded strands and the deflection parameters obtained from analyses were compared with the limit values found in AASHTO LRFD (2012) to determine the suitability of the girders. At the end of the study maximum span length of girders and equation using for calculation for minimum depth of the superstructure of prestressed concrete I-girder bridge were proposed.

Keywords: minimum depth of superstructure; max; span length; prestressed concrete girder; I-CAD

1. Introduction

Prestressed concrete (PSC) I-girder bridges are preferred to construct extensively in medium span (15 m to 40 m) highway bridges. The US national bridge inventory (NBI) and Turkish General Directory of Highways data shows that the PSC bridges cover significant percent of the existing bridges. Lounis and Cohn (1996) emphasized that the PSC I girder bridges are preferred for short and medium spans also preferred for long-span bridges if girder splicing and continuity were introduced. Moravcik (2013), Bujnakova and Strieska (2017) stated that a significant portion of the highway bridges in Slovakia were produced with prestressed concrete technology and that about 200 km of the new bridge, according to recent plans, would be made using PSC technology. It is also clear that the construction of PSC bridges will continue to increase when the increasing transportation needs of the communities and superior properties of PSC are considered. For this reason significant numbers of researchers are working on PSC technology to improve it. Over last decades, countless analytical, numerical and experimental study was conducted on the design parameters, structural and dynamic behavior of PSC. Cohn *et al*. (1994) studied about optimal design of structural concrete bridge systems. Cost of construction, superstructure depth, prestressing steel and amount of concrete were selected as optimization parameters of design. Park *et al*. (2015) proposed minimum shear reinforcement ratio for PSC members. Lou *et al*. (2015) presented their proposed model on nonlinear analysis of PSC continues girder which geometric and material nonlinearity were both taken account. At the end of their study proposed model was validated with some numerical example. Mercan *et al*. (2016) investigated the difference between the arc-length and explicit dynamic finite element model using to static analysis of L-shaped, PSC spandrel beam. Atmaca and Ateş (2017) focused on camber calculation of prestressed concrete I-girder considering geometric nonlinearity. To achieve an economic design and increase the span length of PSC bridge, higher strength strand have been developed. Han *et al*. (2016) investigated the transfer length of high-strength prestressing tendons with a tensile strength of 2400 MPa. They proposed equation to obtain transfer length of high-strength prestressing tendons after experimental study. Carroll *et al*. (2017) compared the behavior of PSC members contain Grade270 and Grade300 prestressing strands, experimentally. Bridge design manual created from Precast/Prestressed Concrete Institute (PCI 2011) provision preliminary design charts for PSC girder. This chart is used only for maximum 55 MPa ultimate strength of concrete and the low-relaxation Grade 270 prestressing strand with of 0.6 in. diameter. Although charts are very helpful for designer, the specific concrete and strand types cause limited use in narrow application. Nowadays high and

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http://www.techno-press.org/?journal=cac&subpage=8 ISSN: 1598-8198 (Print), 1598-818X (Online)

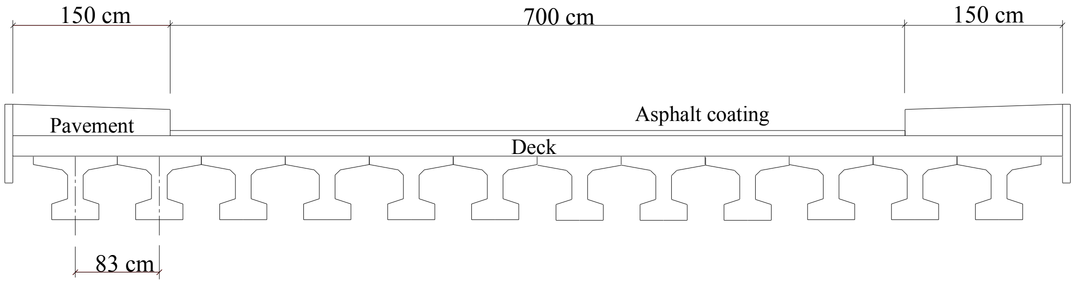

Fig. 1 Cross-section of the selected superstructure (I-60)

ultrahigh strength of concrete and strands are available thanks to developing industrial technology. Marquez *et al*. (2016) proposed new preliminary design charts for normal strength concrete, high performance concrete and ultra-high performance concrete separately with the low relaxation strands which diameters are 0.5, 0.6, and 0.7 in. Also current design codes such as American Association of State Highway Transportation Officials' (AASHTO's) AASHTO LRFD Bridge Design Specifications introduce minimum depth of the superstructure criterion for PSC I-girder bridges for preliminary design. However all design codes have their own parameters such as standard vehicular live load and this may affect the minimum depth of the superstructure criterion. The design truck of AASHTO LRFD is HL93 and the total weight of HL93 is 325 kN. However the total weight of the design truck of Turkish Code, $H_{30}S_{24}$, is 540 kN.

In this paper, the maximum span length of girder and minimum depth of the superstructure of PSC I-girder bridge for different design trucks is aim to determine. For this purpose the widely used superstructure of the I-girder bridge which the girders length was changed by two meter increments between 15 m and 35 m, was taken into account. Twelve girders with different heights which are frequently used in Turkey, were chosen as girder of superstructure. Analyses of the superstructure of PSC I-girder bridge were performed using the I-CAD software program which AASHTO LRFD (2012) conditions were taken into account to a great extent. The dead loads of the structural and non-structural elements forming the bridge superstructure, prestressing force, standard truck load, equivalent lane load and pedestrian load were taken into consideration.

The number of prestressed strands, the number of debonded strands and the deflection parameters obtained from analyses were compared with the limit values stipulated in AASHTO LRFD (2012) to determine the suitability of the girders. At the end of the study maximum span length of girders and equation using for calculation for minimum depth of the superstructure of PSC I-girder bridge were proposed.

2. Superstructure of PSC I-girder Bridge

In general aspect, the bridge superstructure is expressed as the remaining part over the bridge abutments or legs. The depth of superstructure is the summation of the height of girders and the thickness of the deck floor. In this study, the superstructure of the simply supported PSC I-girder was taken into account. Twelve different girders were selected as girder type. The cross-section of the selected bridge superstructure of PSC I-girder bridge in the case of using I-60 girder and general cross-section of the girders used in the bridge superstructure was shown in Fig. 1 and Fig. 2, respectively. The number of girders supporting the bridge deck, center to center distance between the adjacent girders for the selected twelve different girders was given in Table 1. The number of girders used in the bridge superstructure was determined according to top (b_1) and bottom (b_5) flange size of girders. The cross-sectional dimensions of the selected girders were given in Table 2. Material properties considered in the numerical analysis were given in Table 3.

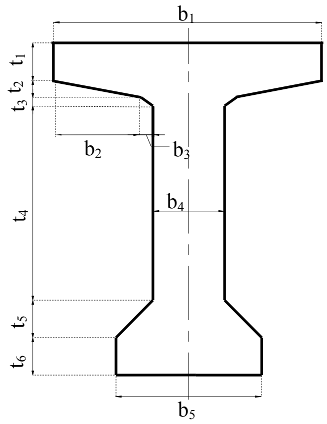

Fig. 2 General cross-section of girders

HL93, design truck of AASHTO and also $H_{30}S_{24}$ design truck of Turkish Code were selected as vehicular live load, separately. Sidewalk load was considered as 3 kN/m^2 distributed load. The relative humidity of construction side was selected as 73%. Prestressing strands placed on the bottom flange of the PSC girder assumed to layout linear along the girder length. Draped strand did not used in girders. Minimum center to center spacing and minimum depth of concrete deck slab was taken into account 5 cm and 17.5 cm according to ASSHTO LRFD (2012), respectively. Transfer length of prestressing tendons not taken into account.

3. Description of basic design constraints

The allowable concrete stress limit, the number of prestressed strands on bottom flange of girder, the number

Table 1 The number of girders supporting the bridge deck and distance between girders

Girder type	Top flange (cm)	Bottom flange (cm)	The number of girders	Distance between girder center (cm)
I-60	80	45	12	83
I-75	75	75	13	77
I-90	80	50	12	83
I-100	95	65	10	100
I-110	80	80	12	83
I-120	75	75	13	77
I-130	80	75	12	83
I-140	80	50	12	83
I-150	80	70	12	83
I-160	80	74	12	83
I-170	190	70	5	200
I-180	120	70	8	125

Table 2 Parameters of girders

Girder type	Cross-sectional dimensions (cm)										
	b_1	b_2	b_3	b_4	b_5	t_1	t_2	t_3	t_4	t_5	t_6
I-60	80	27.5	5	15	45	7.5	5	5	22.5	5	15
I-75	75	27.5	0	20	75	15	10	0	25	10	15
I-90	80	32.5	0	15	50	10	7.5	0	50	7.5	15
I-100	95	32.5	5	20	65	15	6.5	5	46	7.5	20
I-110	80	30	0	20	80	10	7.5	0	70	7.5	15
I-120	75	27.5	0	20	75	10	10	0	75	10	15
I-130	80	30	0	20	75	12	6	0	67	10	35
I-140	80	30	0	18	50	20	11	0	73	16	20
I-150	80	30	0	20	70	20	11	0	74	20	25
I-160	80	30	0	20	74	12	8	0	110	8	22
I-170	190	70	12.5	25	70	7.5	12.5	12.5	92.5	22.5	22.5
I-180	120	32.5	10	35	70	15	15	10	95	20	25

Table 3 Material properties of selected superstructure

Material Properties			Unit
Strand	Type	270K	-
	Ultimate strength	1862	MPa
	Weight per unit volume	78.5	kN/m^3
	Modulus of Elasticity	193053.2	MPa
	Poisson's Ratio	0.3	-
Longitudinal reinforcement of girder	Type	S420	-
	Diameter	16(I) 12(II)	mm
	Weight per unit volume	78.5	kN/m^3
	Modulus of Elasticity	200000	MPa
	Poisson's Ratio	0.3	-
Transverse reinforcement of girder	Type	S420	-
	Diameter	10	mm
	Weight per unit volume	78.5	kN/m^3
	Modulus of Elasticity	200000	MPa
	Poisson's Ratio	0.3	-
Girder concrete	Type	C40/50	-
	Modulus of Elasticity	33836	MPa
	Weight per unit volume	25	kN/m^3
	Poisson's Ratio	0.2	-
Deck concrete	Type	C20/25	-
	Modulus of Elasticity	23926	MPa
	Weight per unit volume	25	kN/m^3
	Poisson's Ratio	0.2	-

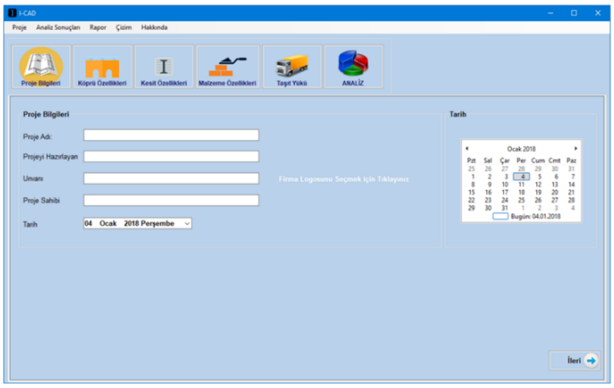

Fig. 3 General view of I-CAD

of debonded strands and the deflection parameters obtained from analyses were compared with the limit values found in AASHTO LRFD (2012) to determine the suitability of the girders. The construction of the superstructure of PSC I-girder bridge consists of some stages. Two of them are detensioning and service stage. In these stages, allowable concrete stresses are different from each other. Also corrosion conditions of prestressing strands or reinforcement is important parameter to determine the allowable concrete tensile stress at service stage. In this study, it was assumed that the bonded prestressing strands or reinforcement were not subjected to worse corrosion

Table 4 Allowable concrete stress at construction stages

Allowable Concrete Stress (MPa)		
Stage	Compression	Tensile
Detensionig	$0.6f_{ci}$	$0.63\sqrt{f_{ci}}$
Service	$0.45f_c$	$0.5\sqrt{f_c}$

conditions. Compression and tensile stress limit of concrete according to ASSHTO LRFD (2012) were given in Table 4. In the construction of PSC girder, prestressing strands are bank up in the bottom flange of the girder to increase the eccentricity of strands to achieve maximum efficiency against the loads. However this application causes to occur excessive stresses at the end zone of girders.

Debonding of strand is used the decrease these excessive stresses to allowable level at the end zone of girders. However the number of debonding of strand is constrained and regulated by ASSHTO LRFD (2012). The deflection caused by live load plus dynamic load allowance shall not exceed one eight hundred span length from center-to-center of supports (L/800) at service limit states.

4. Analysis of superstructure

The analyses of superstructure constructed with different type of girders were performed using I-CAD software (2018). By means of this program, analyses of bridge superstructures with different material properties, span and width under different external influences can be completed quickly and accurately. Also this program performs to report necessary information and draw application projects of the bridge superstructure such as the section properties, internal forces, number of prestressing strand and their placement plan, debonding and deflection parameters, number of reinforcement and their placement on girder and deck (Atmaca 2018). General view of I-CAD menu was shown in Fig. 3.

5. The results of analysis

Bridge superstructure had 10 m width and 0.175 m thickness of deck supported by girders which lengths to vary by two meter increments between 15 m-35 m, were analyzed separately using twelve different girder type. The girders were selected with heights of 60, 75, 90, 100, 110, 120, 130, 140, 150, 160, 170 and 180 cm, which are frequently used in Turkey. As a result of the analyses; the number of prestressed strand used in the girder, the number of strands to be debonded and the deflection occur under live load were controlled with limit values. In the light of these parameters, the suitability of the beams was determined. In this study, the analysis which HL93, design truck of AASHTO and $H_{30}S_{24}$ design truck of Turkish Code taken into account was called Analysis-1 and Analysis-2, respectively. The results obtained from Analysis-1 and Analysis-2 for the bridge superstructure with 15 m span formed using twelve different girders was given in Table 5. In this span all of the selected girders were suitable as seen in Table 5. As girder increase in height, the number of using strand and the deflection of girders decrease. Only one strand was debonded in girder I-60 in this span and debonding was not used in the other girders. Deflection obtained from Analysis-1 was lower than Analysis-2. This is an expected result because the weight of HL93 was lower than $H_{30}S_{24}$ design truck. The number of strand obtained from Analysis-1 for I-75, I-100 and I-120 was lower than Analysis-2. However the number of strand obtained from Analysis-1 and Analysis-2 for other girders is equal the each other.

The results obtained from the analyses of the bridge superstructure with 17 m span formed using twelve different girders were given in Table 6. In this span I-60 girder wasn't suitable because of the number of debonded strand exceed the limit. The number of partially debonded strands should not exceed 25 percent of the total number of strands up to ASSHTO LRFD (2012). The number of strand obtained from Analysis-1 for I-60, I-75, I-120 I-130, I-140, I-150 and I-170 was lower than Analysis-2. The results obtained from the analyses of the bridge superstructure with 19 m span formed using eleven different girders were given in Table 7. In this span girders from I-75 to I-180 were suitable. Only two strands were debonded in girder I-75 in

Table 5 Analysis results for 15 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girde type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-60	7	1	-0.681	Yes	I-60	7	1	-1.129	Yes
I-75	5	-	-0.311	Yes	I-75	6	-	-0.516	Yes
I-90	4	-	-0.264	Yes	I-90	4	-	-0.437	Yes
I-100	4	-	-0.179	Yes	I-100	5	-	-0.296	Yes
I-110	3	-	-0.137	Yes	I-110	3	-	-0.228	Yes
I-120	2	-	-0.112	Yes	I-120	3	-	-0.186	Yes
I-130	2	-	-0.087	Yes	I-130	2	-	-0.145	Yes
I-140	2	-	-0.085	Yes	I-140	2	-	-0.141	Yes
I-150	1	-	-0.060	Yes	I-150	1	-	-0.100	Yes
I-160	1	-	-0.057	Yes	I-160	1	-	-0.095	Yes
I-170	3	-	-0.062	Yes	I-170	3	-	-0.102	Yes
I-180	1	-	-0.042	Yes	I-180	1	-	-0.070	Yes

Table 6 Analysis results for 17 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-60	8	4	-1.044	No	I-60	9	5	-1.733	No
I-75	7	-	-0.477	Yes	I-75	8	-	-0.792	Yes
I-90	6	-	-0.404	Yes	I-90	6	-	-0.670	Yes
I-100	6	-	-0.274	Yes	I-100	6	-	-0.454	Yes
I-110	4	-	-0.211	Yes	I-110	4	-	-0.349	Yes
I-120	3	-	-0.172	Yes	I-120	4	-	-0.285	Yes
I-130	3	-	-0.133	Yes	I-130	4	-	-0.221	Yes
I-140	3	-	-0.130	Yes	I-140	4	-	-0.216	Yes
I-150	2	-	-0.092	Yes	I-150	3	-	-0.153	Yes
I-160	2	-	-0.087	Yes	I-160	2	-	-0.145	Yes
I-170	4	-	-0.094	Yes	I-170	5	-	-0.156	Yes
I-180	3	-	-0.064	Yes	I-180	3	-	-0.107	Yes

Table 7 Analysis results for 19 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-75	10	2	-0.686	Yes	I-75	10	2	-1.139	Yes
I-90	7	-	-0.581	Yes	I-90	8	-	-0.964	Yes
I-100	8	-	-0.393	Yes	I-100	8	-	-0.652	Yes
I-110	6	-	-0.303	Yes	I-110	6	-	-0.502	Yes
I-120	5	-	-0.247	Yes	I-120	5	-	-0.410	Yes
I-130	5	-	-0.192	Yes	I-130	5	-	-0.318	Yes
I-140	5	-	-0.187	Yes	I-140	5	-	-0.310	Yes
I-150	4	-	-0.132	Yes	I-150	4	-	-0.220	Yes
I-160	3	-	-0.126	Yes	I-160	3	-	-0.208	Yes
I-170	6	-	-0.135	Yes	I-170	7	-	-0.223	Yes
I-180	4	-	-0.092	Yes	I-180	5	-	-0.153	Yes

Table 8 Analysis results for 21 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-75	12	4	-0.943	No	I-75	13	5	-1.565	No
I-90	9	3	-0.798	No	I-90	9	3	-1.324	No
I-100	10	-	-0.539	Yes	I-100	10	-	-0.895	Yes
I-110	7	-	-0.415	Yes	I-110	8	-	-0.690	Yes
I-120	6	-	-0.339	Yes	I-120	7	-	-0.562	Yes
I-130	7	-	-0.263	Yes	I-130	7	-	-0.437	Yes
I-140	6	-	-0.256	Yes	I-140	6	-	-0.425	Yes
I-150	5	-	-0.182	Yes	I-150	6	-	-0.302	Yes
I-160	4	-	-0.172	Yes	I-160	5	-	-0.625	Yes
I-170	8	-	-0.184	Yes	I-170	9	-	-0.306	Yes
I-180	6	-	-0.126	Yes	I-180	6	-	-0.209	Yes

this span and debonding was not used in the other girders. The number of strand obtained from Analysis-1 for I-90, I-170 and I-180 was lower than Analysis-2. The results obtained from the analyses of the bridge superstructure with 21 m span formed using eleven different girders were given in Table 8. In this span I-75 and I-90 girders weren't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012). The number of strand obtained from Analysis-1 for I-75, I-110, I-120, I-150, I-160 and I-170 was lower than Analysis-2. The results obtained from the analysis of the bridge superstructure with 23 m span formed using nine different girders were given in Table 9. In this span I-100 wasn't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012). The number of strand obtained from Analysis-1 for I-110 was lower than Analysis-2.

Table 9 Analysis results for 23 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-100	12	4	-0.714	No	I-100	12	4	-1.185	No
I-110	9	-	-0.550	Yes	I-110	10	-	-0.914	Yes
I-120	8	-	-0.449	Yes	I-120	8	-	-0.746	Yes
I-130	9	-	-0.348	Yes	I-130	9	-	-0.579	Yes
I-140	8	-	-0.339	Yes	I-140	8	-	-0.564	Yes
I-150	7	-	-0.241	Yes	I-150	7	-	-0.400	Yes
I-160	6	-	-0.228	Yes	I-160	6	-	-0.379	Yes
I-170	11	-	-0.243	Yes	I-170	11		-0.404	Yes
I-180	8	-	-0.167	Yes	I-180	8	-	-0.277	Yes

Table 10 Analysis results for 25 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-110	11	1	-0.709	Yes	I-110	12	2	-1.178	Yes
I-120	10	-	-0.579	Yes	I-120	10	-	-0.961	Yes
I-130	11	-	-0.449	Yes	I-130	11	-	-0.746	Yes
I-140	9	-	-0.437	Yes	I-140	9	-	-0.726	Yes
I-150	9	-	-0.310	Yes	I-150	9	-	-0.515	Yes
I-160	7	-	-0.294	Yes	I-160	8	-	-0.488	Yes
I-170	13	-	-0.313	Yes	I-170	14	-	-0.519	Yes
I-180	10	-	-0.215	Yes	I-180	11	-	-0.357	Yes

Table 11 Analysis results for 27 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-110	14	4	-0.894	No	I-110	14	4	-1.485	No
I-120	12	2	-0.730	Yes	I-120	13	3	-1.212	Yes
I-130	13	2	-0.566	Yes	I-130	14	3	-0.940	Yes
I-140	11	2	-0.551	Yes	I-140	11	2	-0.916	Yes
I-150	11	-	-0.391	Yes	I-150	11	-	-0.649	Yes
I-160	9	-	-0.370	Yes	I-160	10	-	-0.615	Yes
I-170	16	-	-0.393	Yes	I-170	16	-	-0.653	Yes
I-180	13	-	-0.270	Yes	I-180	13	-	-0.449	Yes

The results obtained from the analysis of the bridge superstructure with 25 m span formed using eight different girders were given in Table 10. In this span girders from I-110 to I-180 were suitable. Only one and two strand was debonded in girder I-110 in this span for Analysis-1 and Analysis-2, respectively. The strands of the other girder weren't debonded. The number of strand obtained from Analysis-1 for I-110, I-160, I-170 and I-180 was lower than Analysis-2. The results obtained from the analysis of the bridge superstructure with 27 m span formed using eight different girders were given in Table 11. In this span I-110 girder wasn't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012). In this span girders from I-120 to I-180 were suitable. Some of strands of I-110, I-120, I-130 and I-140 were debonded. The number of strand obtained from Analysis-1 for I-120, I-130 and I-160 was lower than Analysis-2. The results obtained from the analysis of the bridge superstructure with 29 m span formed using seven different girders were given in Table 12. In this span I-120 girders wasn't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012). The results obtained from the analysis of the bridge superstructure with 31 m span formed using six different girders were given in Table 13. In this span I-130 and I-140 girders weren't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012). The results obtained from the analysis of the bridge superstructure with 33 m span formed using four different girders were given in Table 14. In this span I-150 girder wasn't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012) both Analysis-1 and Analysis-2. However I-170 and I-180 girders weren't suitable because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012) for Analysis-2. The results obtained from the analysis of the bridge superstructure with 35 m span formed using three

Table 12 Analysis results for 29 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-120	14	6	-0.903	No	I-120	14	6	-1.500	No
I-130	16	4	-0.700	Yes	I-130	16	4	-1.162	Yes
I-140	13	3	-0.682	Yes	I-140	13	3	-1.132	Yes
I-150	13	2	-0.483	Yes	I-150	13	2	-0.803	Yes
I-160	11	-	-0.458	Yes	I-160	12	-	-0.761	Yes
I-170	19	-	-0.485	Yes	I-170	20	2	-0.806	Yes
I-180	15	-	-0.334	Yes	I-180	15	-	-0.554	Yes

Table 13 Analysis results for 31 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-130	19	7	-0.852	No	I-130	19	7	-1.415	No
I-140	15	5	-0.830	No	I-140	16	6	-1.379	No
I-150	15	3	-0.588	Yes	I-150	15	3	-0.977	Yes
I-160	13	1	-0.558	Yes	I-160	14	2	-0.926	Yes
I-170	22	4	-0.589	Yes	I-170	23	4	-0.979	Yes
I-180	18	4	-0.406	Yes	I-180	18	4	-0.674	Yes

Table 14 Analysis results for 33 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-150	17	5	-0.706	No	I-150	18	6	-1.173	No
I-160	16	3	-0.670	Yes	I-160	16	3	-1.112	Yes
I-170	26	6	-0.706	Yes	I-170	27	7	-1.173	No
I-180	21	5	-0.487	Yes	I-180	22	6	-0.808	No

Table 15 Analysis results for 35 m girder length

Analysis-1					Analysis-2				
Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability	Girder type	Number of strand	Number of debonded strand	Deflection (cm)	Suitability
I-160	18	5	-0.795	No	I-160	19	5	-1.321	No
I-170	28	8	-0.707	No	I-170	30	9	-1.279	No
I-180	24	8	-0.577	No	I-180	25	9	-0.958	No

different girders were given in Table 15. All of the selected girders weren't suitable for this span because of the number of debonded strand exceed the limit of ASSHTO LRFD (2012).

As the results obtained from all analyses were examined, the suitable spans length for selected twelve girders up to Analysis-1 and Analysis-2 were given as in Table 16 and 17, respectively. Although the number of calculated strand was different in both analyses, the minimum height of girder corresponding to the selected span was the same. Proposed equation using for calculation for minimum depth of the superstructure of prestressed concrete I-girder bridge was determined by regression analysis based on the values given in Table 15 and Table 16 and the thickness of the deck slab.

The minimum depth of the superstructure for span ranging from 15 m to 33 m obtained from analyses and the

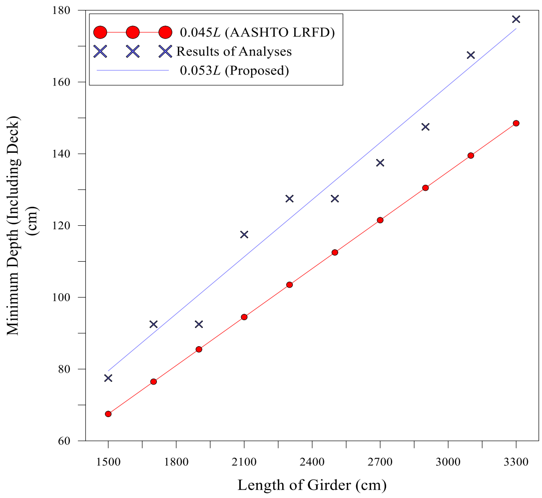

Fig. 4 The relationship between girder length and depth of superstructure

Table 16 The available spans length up to Analysis-1

Girder type	Span										
	15 m	17 m	19 m	21 m	23 m	25 m	27 m	29 m	31 m	33 m	35 m
I-60	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
I-75	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
I-90	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
I-100	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
I-110	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
I-120	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗
I-130	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
I-140	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
I-150	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗
I-160	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
I-170	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
I-180	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗

Table 17 The available spans length up to Analysis-2

Girder type	Span										
	15 m	17 m	19 m	21 m	23 m	25 m	27 m	29 m	31 m	33 m	35 m
I-60	✓	✗	✗	✗	✗	✗	✗	✗	✗	✗	✗
I-75	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
I-90	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗	✗
I-100	✓	✓	✓	✓	✗	✗	✗	✗	✗	✗	✗
I-110	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗	✗
I-120	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗	✗
I-130	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
I-140	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗	✗
I-150	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗
I-160	✓	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗
I-170	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗
I-180	✓	✓	✓	✓	✓	✓	✓	✓	✓	✗	✗

regression curve determined from these values were given in Fig. 5. Also minimum depth of the superstructure determined by equation recommended by AASHTO LRFD added to Fig. 4. It is clearly seen that the proposed equation is more conservative than equation recommended by AASHTO LRFD.

6. Conclusions

The aim of this paper is to determine the maximum span length of girders and minimum depth of the superstructure of prestressed concrete I-girder bridge. For this purpose the superstructure of the bridge with the width of 10 m and the thickness of the deck floor of 0.175 m, which the girder length was changed by two meter increments between 15 m and 35 m, was taken into account. Twelve different girders which are frequently used in Turkey, were chosen as girder type. The analyses of the superstructure of prestressed concrete I-girder bridge were conducted with I-CAD software. The dead loads of the structural and non-structural elements forming the bridge superstructure, prestressing force, standard truck load, equivalent lane load and pedestrian load were taken into consideration. All design codes have their own standard vehicular live load and this may affect the minimum depth of the superstructure criterion. HL93, design truck of AASHTO and also $H_{30}S_{24}$ design truck of Turkish Code were selected as vehicular live load. The allowable concrete stress limit, the number of prestressed strands, the number of debonded strands and the deflection parameters obtained from analyses were compared with the limit values found in AASHTO LRFD (2012) to determine the suitability of the girders. At the end of the study suitable span length of girders and equation using for calculation for minimum depth of the superstructure of prestressed concrete I-girder bridge were proposed. The results obtained from this study make it possible to draw the following conclusions:

- As the girder height increases, the number of prestressing strands decreases so the beam works as reinforced concrete. At the same time, the deflection in the girder decreases too.
- As the results obtained from Analysis 2, which was heavier design truck $H_{30}S_{24}$ was taken into consideration compared than the results obtained from Analysis 1, it is seen that the number of calculated strands is higher in many girders and the deflection obtained in the middle of the girders increase.

• The allowable concrete stress limit, the number of prestressed strands, the number of debonded strands and the deflection parameters obtained from analyses were compared with the limit values found in AASHTO LRFD (2012) to determine the suitability of the girders. Result of all analyses shows that the debonded limit of AASHTO LRFD is solitary determinant parameter to determine the suitability of the girders. For all unsuitable girder, partially debonded strands exceed 25 percent of the total number of strands. The percentage of this debonded limit will be examined in new studies. Increasing of this percentage will provide the decreasing of minimum depth of the superstructure.
• According to both analyses, proposed equation using for calculation for minimum depth of the superstructure of prestressed concrete I-girder bridges is same.
• The proposed equation using for calculation for minimum depth of the superstructure of prestressed concrete I-girder bridge is more conservative than equation recommended by AASHTO LRFD (2012).

Acknowledgments

The created program (I-CAD) using in the paper is part of a Ph.D thesis prepared by B. Atmaca under the direction of Ş. Ateş in the Department of Civil Engineering, Karadeniz Technical University, Trabzon, Turkey.

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