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STUDY ON THE APPLICATION OF AASHTO-LRFD AND SCT STANDARDS FOR THE DESIGN OF PRESTRESSED CONCRETE BRIDGES IN MEXICO

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Abstract: The AASHTO-LRFD (American Association of State Highway and Transportation Officials - Load and Resistance Factor Design) and SCT (Secretaría de Comunicaciones y Transportes) standards provide guidelines for the design and construction of prestressed concrete bridges. The analysis of the application of the AASHTO-LRFD and SCT standards for the design of prestressed concrete bridges in Mexico is fundamental to determine the feasibility of implementing an improved standard in Mexico. In Mexico, the application of these standards is critical due to the challenges posed by overweight truck traffic and the deteriorating state of the bridge and roadway network. The AASHTO-LRFD standard is applicable for various beam spacings and spans, while the SCT tends to take a more conservative approach, particularly in load distribution factors and design parameters. In this analysis, the design criteria for prestressed concrete bridges established by the AASHTO-LRFD and the SCT were studied and applied in order to evaluate their applicability in Mexico and to determine if they are adequate for the vehicular traffic and the type of roads in the country. It was determined that one of the main differences between the two standards lies in their load distribution factors (LDF). The SCT FDC is generally more conservative by an average of 15% compared to AASHTO-LRFD when beam spacings exceed 2.4 meters. This conservative approach results in SCT requiring more strands in the design, which can lead to higher material costs and oversized structures. In contrast, the AASHTO-LRFD considers additional factors such as geometric properties and stiffness of composite beam and slab sections, allowing for a more optimized design that leads to a reduction in materials and a decrease in time and cost of fabrication and erection of structural elements. The applicability of the AASHTO-LRFD and SCT standards was also found to be influenced by beam spacing and span length. AASHTO-LRFD is suitable for beam spacings up to 2.4 meters and spans less than or equal to 30 meters for Type A and C roads. In comparison, SCT design criteria are more restrictive, particularly for heavier trucks, which can limit the flexibility of bridge design. As beam spacing decreases, the differences in the number of strands required between the two standards decrease, suggesting that AASHTO-LRFD may be more effective for smaller spacings. In conclusion, while the AASHTO-LRFD and SCT standards aim to ensure the safety and reliability of prestressed concrete bridges, their different approaches to load distribution, design parameters and strength criteria highlight the need for further research and optimization. The increasing prevalence of overweight vehicles in Mexico poses significant challenges to the effectiveness of both standards, necessitating a reevaluation of design practices. Future studies should focus on integrating finite element analysis and exploring alternative beam types to improve the performance and sustainability of bridge designs in Mexico.

INTRODUCTION

In 1962, the regulations and instructions on the weight and dimensions of vehicles were implemented to regulate highway operations. In 1991, the Secretariat of Communications and Transportation (SCT) began to study the weights and dimensions of cargo vehicles circulating on national highways. At that time, the national highway network was 46,000 km long. It was identified that, in general, cargo vehicles circulated with an overweight level of around 50%. The Mexican regulation focuses on pavement damage, in contrast to the U.S. regulation which focuses on protecting infrastructure and limiting damage to bridges, considering that these are the most vulnerable and important elements to protect. On September 4, 1995, the Secretary of Communications and Transportation (SCT) published in the Official Gazette of the Federation the Mexican regulation on loads and dimensions, which establishes the regulations on the loads and dimensions that vehicles must comply with on highways under federal jurisdiction. In 1997, Mexico still did not have its own regulations for the design and revision of bridges. For a long time, the lack of criteria and regulations in Mexico led bridge designers to opt for hybrid methodologies or to apply design vehicles from foreign regulations to determine the Load Distribution Factors (LDF). Currently, Mexico has the SCT (2004) standard derived from the AASHTO-ASD simplified "D" value methods (simplified procedure to determine the mechanical effects on the longitudinal beams of the superstructure of a bridge). Based on the study presented by Delgado (2018) on the evaluation of load distribution factors in prestressed bridges in Mexico and considering the existing problem of overweight in the Highway Network in Mexico, it is hypothesized that the AASHTO-LRFD standard is applicable in Mexico for prestressed concrete bridges using "AASHTO I" type girders with spans no greater than or equal to 30 m.

In order to evaluate the feasibility of the AASHTO-LRFD standard in the design of prestressed concrete bridges in Mexico using AASHTO Type I beams, a comparative study was carried out based on data from the Sistema de Puentes en México (SIPUMEX). These data cover a specific range of spans, between 15m and 30m, with beam spacings from 1.8m to 3.6m and AASHTO Type II-VI beams, which are indispensable for the analysis of the application of the AASHTO-LRFD design code in bridge design.

PREDOMINANT GEOMETRIC CHARACTERISTICS OF PRESTRESSED BRIDGES IN MEXICO

In order to evaluate the suitability of the AASHTO-LRFD standard in the design of prestressed concrete bridges in Mexico using AASHTO Type I beams, a comparative study was carried out using information from The Bridge System in México (El Sistema de Puentes en México, SIPUMEX). This information covers a specific range of spans from 15m to 30m, with beam spacings from 1.8m to 3.6m and AASHTO Type II-VI beams.

By analyzing Figure 2.1, it can be determined that 43% of the prestressed concrete bridges have only one span. Figure 2.2 illustrates the percentage of prestressed bridges and their corresponding span length.

Based on Figure 2.2 it is determined that 76% of these bridges have a length of less than 30 meters. Figures 2.3, 2.4 and 2.5 illustrate the spacings between beams for prestressed concrete bridges with widths of 7.5-10m, 10-15m, and 15-20m respectively.

Beam spacing for a width of 7.5 to 10 m

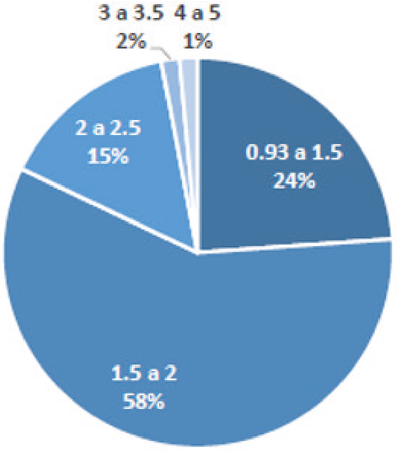

Figure 2.3. Girder spacings for bridges with a width of 7.5-10m (SIPUMEX 2010) (Delgado et al., 2018).

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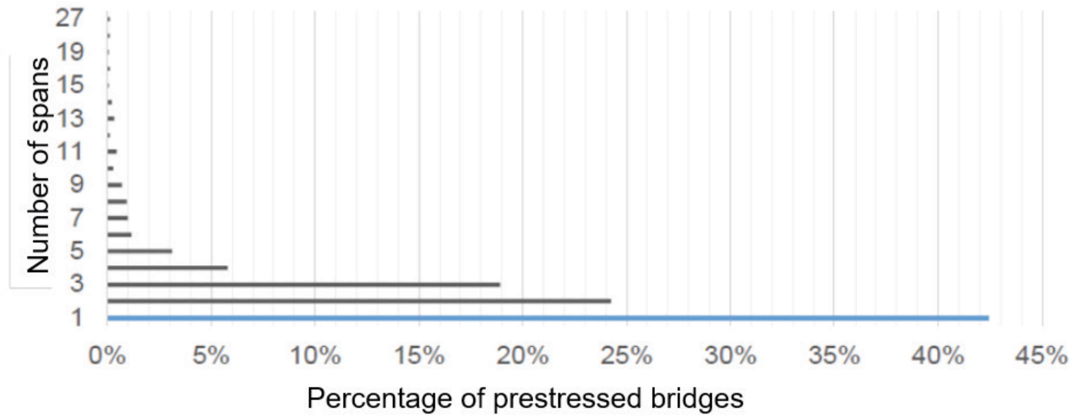

Figure 2.1 shows the percentage of prestressed bridges corresponding to the number of spans it has (SIPUMEX 2010) (Delgado et al., 2018).

Percentage of prestressed bridges vs. number of spans (SIPUMEX 2010) (Delgado et al., 2018).

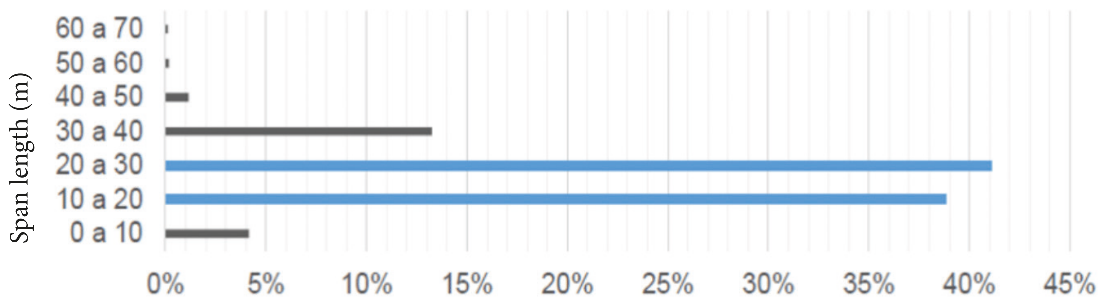

Figure 2.2. Percentage of prestressed bridges and corresponding span length (SIPUMEX 2010) (Delgado et al., 2018).

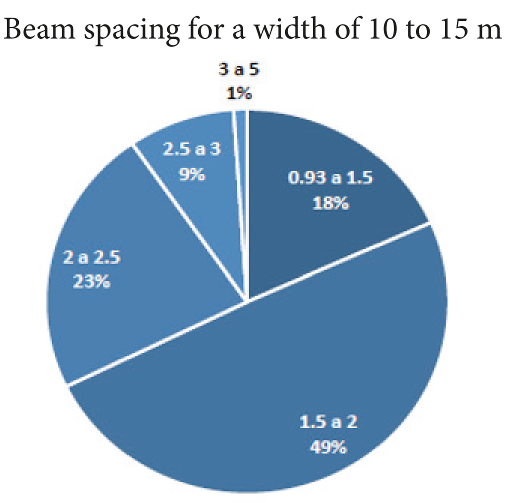

Figure 2.4. Girder spacings for bridges with a width of 10-15m (SIPUMEX 2010) (Delgado et al., 2018).

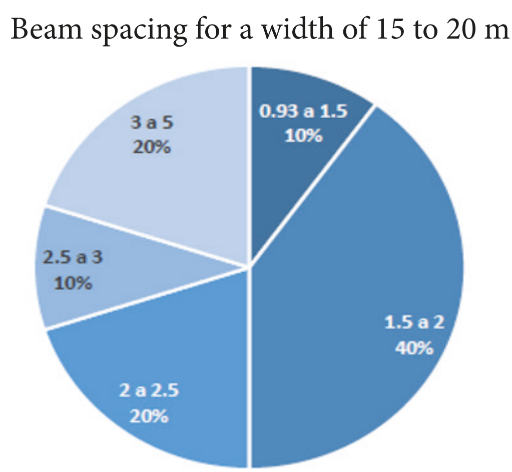

Figure 2.5. Girder spacings for bridges with a width of 15-20m (SIPUMEX 2010) (Delgado et al., 2018).

By analyzing Figures 2.3-2.5, it can be determined that 90% of the bridges have a separation between beams equal to or less than 3.6 m. Based on the analysis and observations made, it can be concluded that the predominant geometric characteristics of prestressed concrete bridges in Mexico are: having a single span, having a length equal to or less than 30 meters and having a maximum separation between beams of 3.6 m. Based on these characteristics, a study will be carried out to determine the scope of application of the AASHTO-LRFD and SCT Standards for the design of prestressed concrete bridges in Mexico.

VEHICULAR LOADS AND DESIGN METHODOLOGY OF THE AASHTO-LRFD AND THE SCT IN MEXICO

Bridge design in Mexico is based on regulations that encompass both the AASHTO--LRFD (Load and Resistance Factor Design) approach and the specifications of the Secretariat of Communications and Transportation (SCT). The main characteristics of both methodologies are described below.

AASHTO-LRFD

The AASHTO-LRFD approach, introduced by the American Association of State Highway and Transportation Officials (AASHTO) in 1994, represents a contemporary perspective based on the combination of loadings and Limit state analysis for both strength and serviceability. Its main objective is to improve the safety and efficiency of bridge design. The HL-93 load is used for structural design. This load includes combinations of design trucks considering factors like ductility, redundancy, and structural importance, which enhance safety in bridge design.

Live load model AASHTO HL-93

The vehicular live load is represented by the load denominated HL-93, which is formed by the combination of effects of the following vehicular loads:

a.) HS-20 design truck + lane load

b.) Tandem design truck + lane loading

The most unfavorable load combination is considered for the bridge design.

HS-20 Design Truck

The HS-20 design truck has a total weight of 72 kip (32.7 ton). Its weight distribution along its length and tire wheelbase is shown in Figure 3.1.

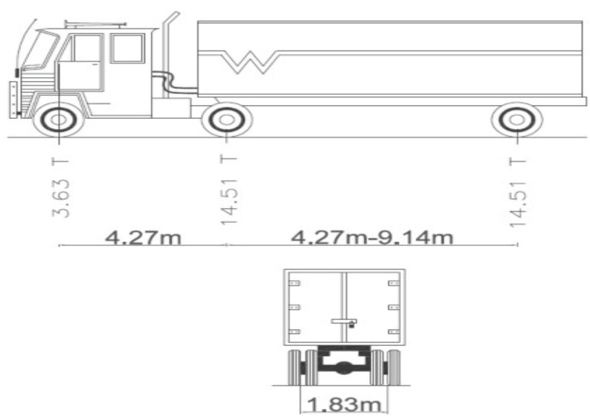

Figure 3.1 HS-20 Design Truck (AASHTO-LRFD 2020)

Tandem Design Truck

The Tandem design truck consists of two cargo axles of 25 kip (11,350 kg) each, with a wheelbase of 4ft (1.2m) and a transverse separation of 6ft (1.8m).

Load Lane

The lane load is part of the HL-93 load defined by AASHTO and is defined as a load uniformly distributed over a length "L" and width of 10 ft (3.05 m) and equal to 0.64 kip/ft (953.3 k/m).

SCT METHODOLOGY

The SCT has used the allowable stress design (ASD) method as a conventional practice, and has started to integrate aspects of the LRFD design method. Despite this, implementation of LRFD is not as common, as there is a lack of comprehensive standards for wider application.

IMT Live Load Model

The IMT (Mexican Transport Institute) created a live load model in Mexico to represent the T3-S3 and T3-S2-R4 trucks. These models are considered for the longitudinal, transverse and three-dimensional analyses of the superstructure, taking into account the live loads due to the vehicles described below:

- IMT 66.5 Models: These are suitable for use on bridges designed for type ET, A, B and C highways, based on the classification of the Regulation on the weight, dimensions and capacity of motor vehicles traveling on roads and bridges under federal jurisdiction. They are also applicable to highways, which are type ET and A roads, with controlled access.
- IMT 20.5 Models: Valid for the construction of bridges for type D highways, based on the categorization set forth in the regulations on the weight, dimensions and capacity of transport vehicles that circulate on roads and bridges under federal jurisdiction, as well as for rural trails.

Model IMT 66.5

The IMT 66.5 model is used for longitudinal analysis for spans of 30 m or more, including three concentrated loads (P1, P2, P3) and a uniformly distributed load w (Figure 3.2). In the case of Type C roads, the loads must be reduced by a factor of nine tenths (0.9).

Where P1 = 49 kN (5 ton), P2 = 235 kN (24 ton), P3 = 368 kN (37.5 ton). For spans equal to or greater than ninety (90) meters, the load w = 10 kN/m (1 ton/m) and for spans between thirty (30) and ninety (90) meters, the load w = 10(L-30) /60 (kN/m).

For spans less than 30 m, w = 0 and P2 is divided into two 2 equal charges of 118 kN (12 ton) and P3 is divided into three equal loads of 123 kN (12.5 ton), in both cases, spaced 1.2 m apart, as shown in Figure 3.3.

IMT Model 20.5.

For spans equal to or greater than 15 meters, the IMT 20.5 model consists of two concentrated loads, $_{P4}$ = 25 kN (2.5 ton) and $_{P5}$ = 177 kN (18 ton), and a uniformly distributed load w' = 8.8 kN/m (0.9 ton/m) as shown in Figure 3.4.

For spans less than 15 meters, the P5 value is split into two 88 kN (9 ton) loads, separated by a distance of 1.2 meters, and a uniformly distributed load w' = 8.8L/15 (SCT 2004), where L is the span length (Figure 3.5).

DESCRIPTION OF THE MECHANICAL PROPERTIES AND DESIGN PARAMETERS

This section describes the geometric characteristics and design parameters used to study the scope of the AASHTO-LRFD standards in the design of prestressed concrete bridges in Mexico.

BRIDGE CROSS SECTION

Figure 4.1 represents the "type" bridge cross-section selected for this study. The "S" spacings between girders were considered to be 6, 8 and 10 ft (1.8 m, 2.4 m, 3.0 m). The girders used were AASHTO II-VI type girders with lengths of 50 to 100 ft (15 to 30 m) with a single span and simply supported at their ends. Based on PCI (2017) specifications, a slab thickness of 8 in. (20.32 cm) was determined.

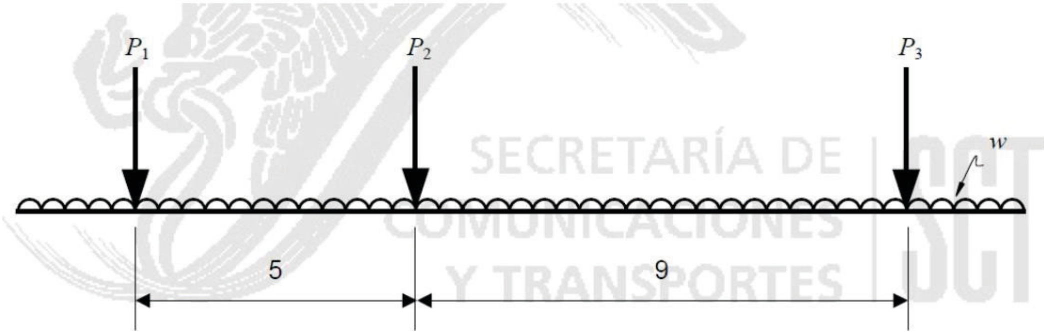

Figure 3.2 IMT 66.5 model for spans equal to or greater than 30 m (SCT 2004).

Dimensioning in m.

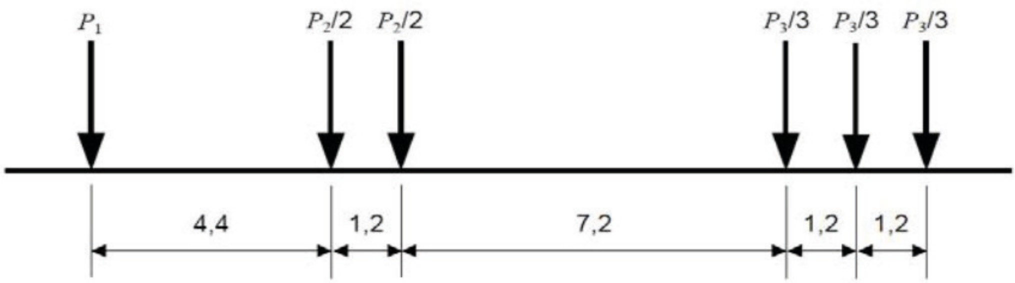

Figure 3.3 IMT 66.5 model for clearings less than 30 m (SCT 2004).

Dimensioning in m.

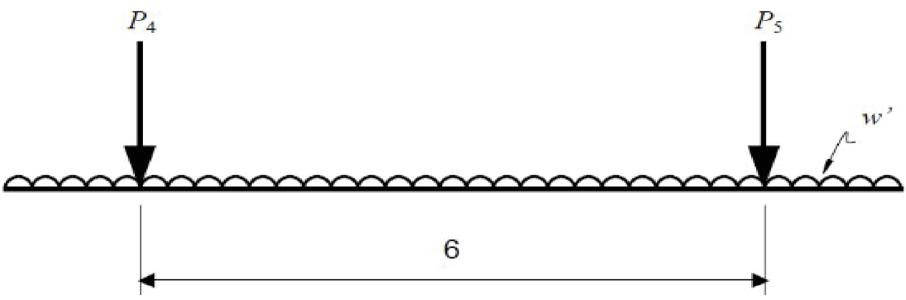

Figure 3.4 IMT 20.5 model for spans equal to or greater than 15 m (SCT 2004).

Dimensioning in m.

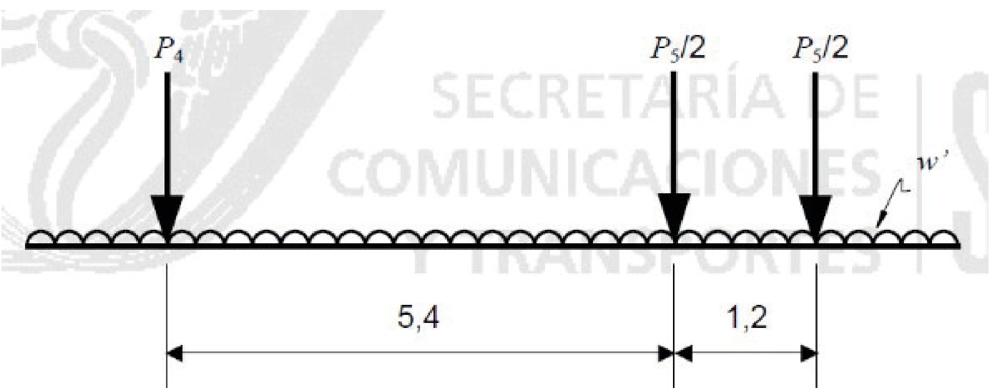

Figure 3.5 IMT 20.5 model for clearings less than 15 m (SCT 2004).

Dimensioning in m.

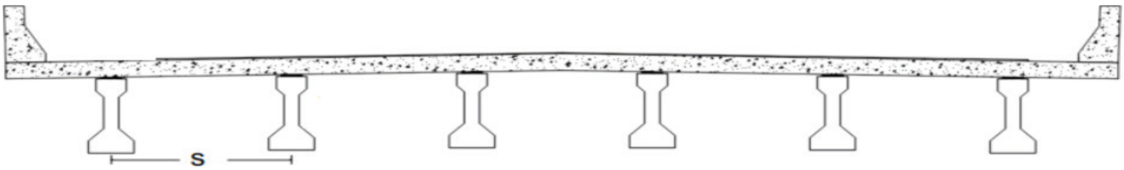

Figure 4.1 “Type” Bridge Cross Section

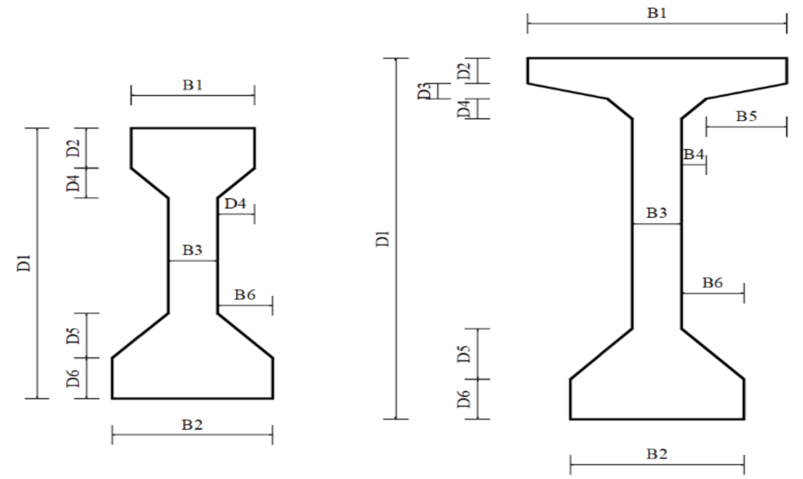

Figure 4.2 AASHTO Type II-VI Beams

Dimensions (inches)

Type	D1	D2	D3	D4	D5	D6	B1	B2	B3	B4	B5	B6
I	28	4	0	3	5	5	12	16	6	3	0	5
II	36	6	0	3	6	6	12	18	6	3	0	6
III	45	7	0	4.5	7.5	7	16	22	7	4.5	0	7.5
IV	54	8	0	6	9	8	20	26	8	6	0	9
V	63	5	3	4	10	8	42	28	8	4	13	10
VI	72	5	3	4	10	8	42	28	8	4	13	10

Table 4.1 AASHTO Type II-VI Beam Dimension Table

Properties:

Type	Area in.^{2}	y_{bottom} in.	Inertia in.^{4}	Weight kip/ft
I	276	12.59	22,750	0.287
II	369	15.83	50,980	0.384
III	560	20.27	125,390	0.583
IV	789	24.73	260,730	0.822
V	1,013	31.96	521,180	1.055
VI	1,085	36.38	733,320	1.13

According to the specifications in the PCI Manual (2017), a reinforced concrete slab thickness of 8 inches (203 mm) was selected for beam spacings of 6, 8, and 10 feet (1.8 m, 2.4 m, and 3.0 m). For the limit state analysis, a concrete compressive strength of 4,000 psi (28 MPa) at 28 days was used. Additionally, a reduction of ½ inch (13 mm) in slab thickness was implemented to assess the structural properties.

Table 4.2 Table of properties of AASHTO Type II-VI Beams

Figure 4.2 shows the AASHTO II-VI type beams selected for the study. The geometric characteristics and mechanical properties are shown in Tables 4.1 and 4.2.

The 28-day compressive strength of the AASHTO beams was considered to be f'_c = 8 ksi i (55 MPa) and with a compressive strength of f'_{ci} = 6.8 ksi (46.9 MPa) at strand release. Based on the AASHTO LRFD Bridge Design Specifications (2020), the allowable tensile stresses were 7.5 $\sqrt{f'_{ci}}$ psi (0.63 $\sqrt{f'_{ci}}$ MPa) at prestress release and 6 $\sqrt{f'_c}$ psi (0.5 $\sqrt{f'_c}$ MPa) for working stresses. Likewise, the allowable compressive stresses were 0.6 f'_{ci} at prestress release and 0.6 f'_c for working stresses.

REINFORCED CONCRETE SLAB

According to the specifications in the PCI Manual (2017), a reinforced concrete slab thickness of 8 inches (203 mm) was selected for beam spacings of 6, 8, and 10 feet (1.8 m, 2.4 m, and 3.0 m).

For the limit state analysis, a concrete compressive strength of 4,000 psi (28 MPa) at 28 days was used. Additionally, a reduction of ½ inch (13 mm) in slab thickness was implemented to assess the structural properties.

REINFORCING STRANDS

The bridge design was developed with seven-wire, 0.6 in (13 mm) diameter, and 270 ksi (1.86 GPa) low-relaxation strands. The center-to-center spacing of the strands was 2 in (51 mm), and all strands were assumed to have an initial tension of 202.5 ksi (1.40 GPa) prior to release. To calculate prestressing losses, the approximate AASHTO method specified in LRFD Article 5.9.5.3 was employed, taking into account a relative humidity of 70%.

PERMANENT LOADS FOR COMPOSITE AND NON-COMPOSITE SECTIONS

The weights of the beams, slabs, and haunches were considered as dead loads acting on the non-composite cross-section of the bridge before the hardening of the slab concrete. For the dead load acting on the composite bridge cross-section after the concrete slab had hardened, values of 0.5 kip/ft (744.8 kg/m) for the weight of the parapets and 0.035 ksf (171 kg/m^2) for the bearing surface were assumed.

COMPARATIVE STUDY OF THE USE OF AASHTO-LRFD AND SCT DESIGN STANDARDS

In this section, a comparative analysis between the AASHTO-LRFD and SCT standards is performed. The purpose is to determine the scope of the AASHTO-LRFD Standard in the design of prestressed concrete bridges in the National Territory. For this study, the AASHTO-LRFD (2020) and SCT (2004 and 2016) design specifications were used as well as the mechanical properties and design parameters described in Section 4 of this document. Due to publication space issues, AASHTO Type II, and VI beams were selected for the comparative study shown below. However, it should be emphasized that the study also covered AASHTO type II III, and V beams. The results for AASHTO Type II beams are shown below.

AASHTO TYPE I BEAMS

The comparison of the bending moments at the center span of the AASHTO Type II beam caused by permanent loads and the HL-93, IMT 66.5 and IMT 20.5 live loads is shown in Figure 5.1. Based on the AASHTO-LRFD specifications, the maximum length determined for the AASHTO Type II beams was 22.5 m (74 ft). The design standards used were the AASHTO-LRFD for the HL-93 load and the SCT standards for the IMT-66.5 and IMT-20.5 loads.

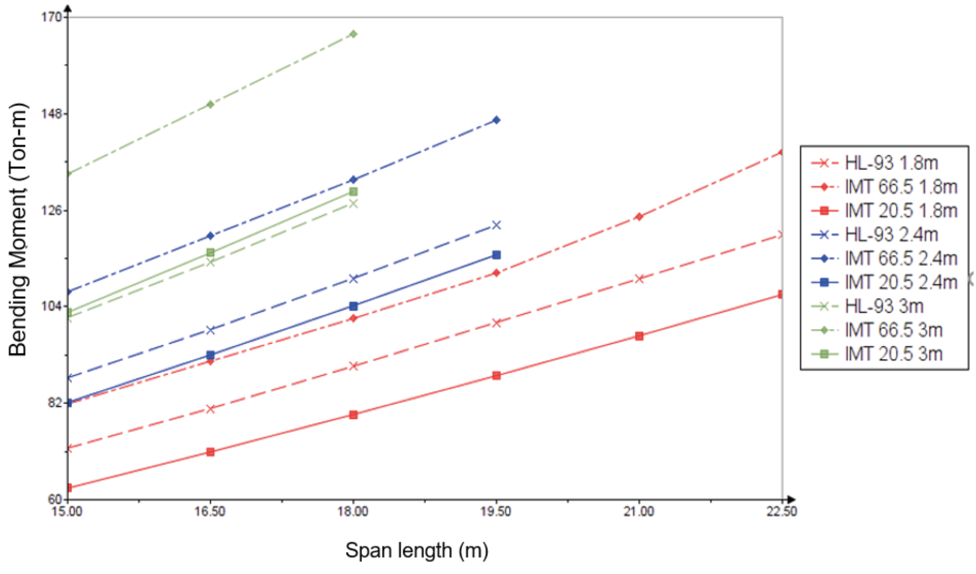

Figure 5.1 Bending moments at center span for AASHTO Type II beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to HL-93, IMT 66.5 and IMT 20.5 design loads.

		Bending moments at midspan with impact due to design loads, ton-m.			Difference between bending moments.			
					HL-93 vs IMT 66.5		HL-93 vs IMT 20.5	
Interval between clearings, m	Beam spacing, m	HL-93	IMT 66.5	IMT 20.5	Difference	%	Difference	%
15-22.5	1.80	95.700	108.380	84.230	12.680	13.25	11.470	11.99
15-19.5	2.40	105.000	126.770	98.810	21.770	20.73	6.190	5.90
15-18	3.00	114.450	150.210	116.420	35.760	31.25	1.970	1.72

Table 5.1 Comparison of bending moments at center span of AASHTO II beam due to HL-93, IMT 666.5 and IMT-20.5 loads.

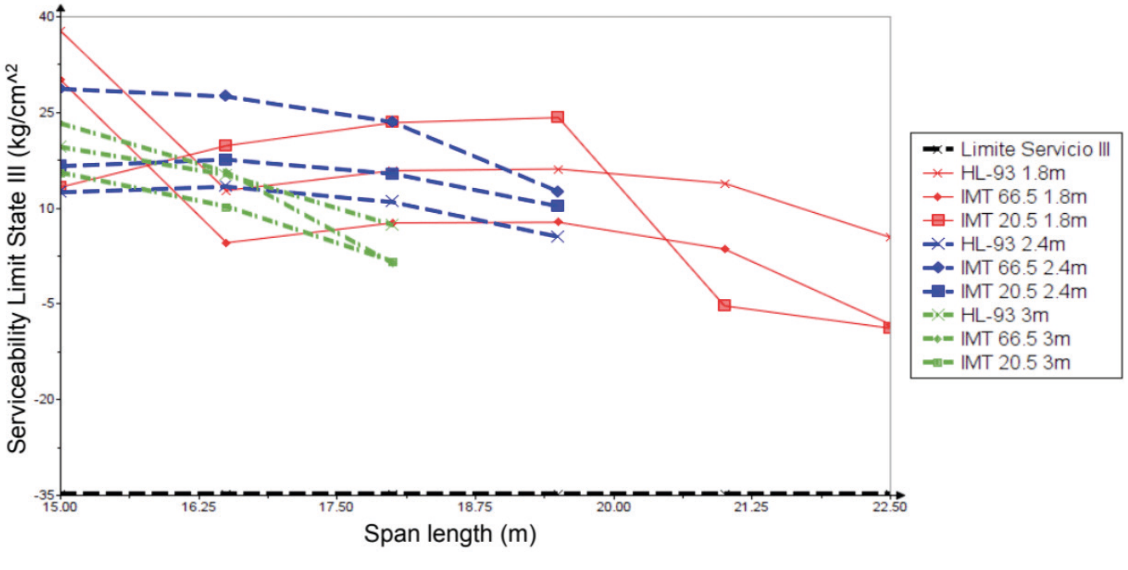

Figure 5.2. Serviceability limit state III (stresses at center of span) for AASHTO Type II beam with 6, 8 and 10 ft (1.8m, 2.4m and 3m) beam spacings due to design loads HL-93, IMT 66.5 and IMT 20.5.

Table 5.1 was developed based on Figure 5.1.

The results in Figure 5.1 and Table 5.1 show that as the spacing between the beams increases, the difference between the bending moments originated by the design loads HL-93 and IMT 66.5 also increases. The difference varies with the distance between the beams. For a spacing of 1.8m, the difference is 13.25%, while for a spacing of 3m, the difference increases to 31.25%. However, the difference between the bending moments generated by the HL-93 and IMT 20.5 loads decreases as the beam spacing increases. The variation ranges from 12% for a spacing of 1.8m, to 1% when the spacing is 3m. Therefore, the HL-93 design load could be applied to prestressed concrete bridges requiring the IMT 20.5 design load, which is used in the design of Type D highway bridges.

The limit state III review was performed to ensure that the stresses generated by the permanent and vehicular loads did not exceed the allowable tensile stresses established by the AASHTO-LRFD specifications. As an example, Figure 5.2 shows the stresses generated at the center of the AASHTO Type II beams by the design loads (HL-93, IMT 66.5 and IMT 20.5) using the AASHTO-LRFD and SCT standards.

None of the stresses shown in Figure 5.2 exceed the allowable stress limit ($-0.19(f'c)^{0.5} = -35 kg/cm^2$ ($3.43\ MPa$)) established in the AASHTO-LRFD [LRFD Art. 5.9.4.2] for serviceability limit state III. The sign of the stress indicates whether it is in compression (+) or tension (-). Figures 5.3 and 5.4 show the comparative ultimate shear and the required shear reinforcing steel.

The data shown in Table 5.2, obtained from Figures 5.3 and 5.4, indicate that the IMT 66.5 load requires, on average, 45.4% more shear reinforcing steel compared to the HL-93 load (Figure 5.4 and Table 5.2).

AASHTO TYPE VI BEAMS

The comparison of the bending moments at the center span of the AASHTO type VI beam caused by permanent loads and the HL-93, IMT 66.5 and IMT 20.5 live loads is shown in Figure 6.1. The maximum length considered for the AASHTO type VI beams was 33 m (108 ft). This is because the loading configuration of IMT 66.5 changes for lengths greater than 30 m and results in bending moments considerably greater than those produced by the HL-93 load. Consequently, scoping the AASHTO-LRFD standards for spans greater than 30 m would no longer make sense. The design standards used were the AASHTO-LRFD for the HL-93 load and the SCT standards for the IMT-66.5 and IMT-20.5 loads.

Table 6.1 is based on Figure 6.1.

The results show that as the distance between beams increases, the difference between the bending moments generated by the design loads HL-93 and IMT 66.5 increases. This difference varies from 4.71% when the spacing between beams is 1.8 m to 24.95% when the spacing is 3.6 m and the span is less than 30 m. In cases where the span is equal to or greater than 30 m, the differences range from 28.68% when the separation between beams is 1.8 m to 62.93% when the separation is 3.6 m. This difference is due to the change in the IMT 66.5 load configuration. However, the difference between the bending moments caused by the HL-93 and IMT 20.5 loads decreases as the beam spacing increases. This difference varies from 24.16% when the beam spacing is 1.8m to 2% when the spacing is 3.6m. In summary, the HL-93 design load could be used for the design of prestressed concrete bridges where the IMT 20.5 design load is required, which is used in the design of bridges intended for type D roads.

Figure 6.2 shows a comparison of the maximum shear force values for the AASHTO Type VI beam caused by HL-93, IMT66.5 and IMT 20.5 loads.

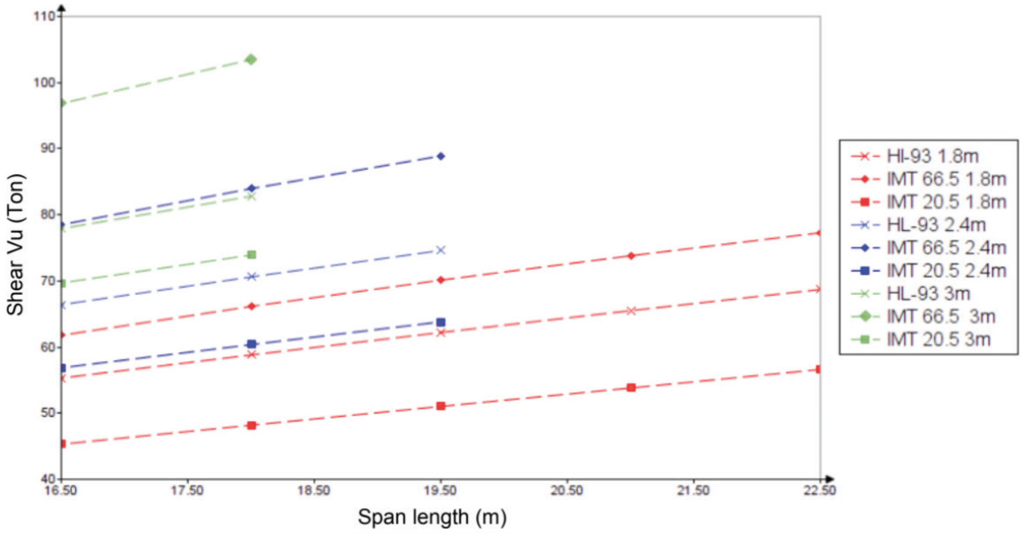

Figure 5.3. Ultimate shear vs span length for AASHTO Type II beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

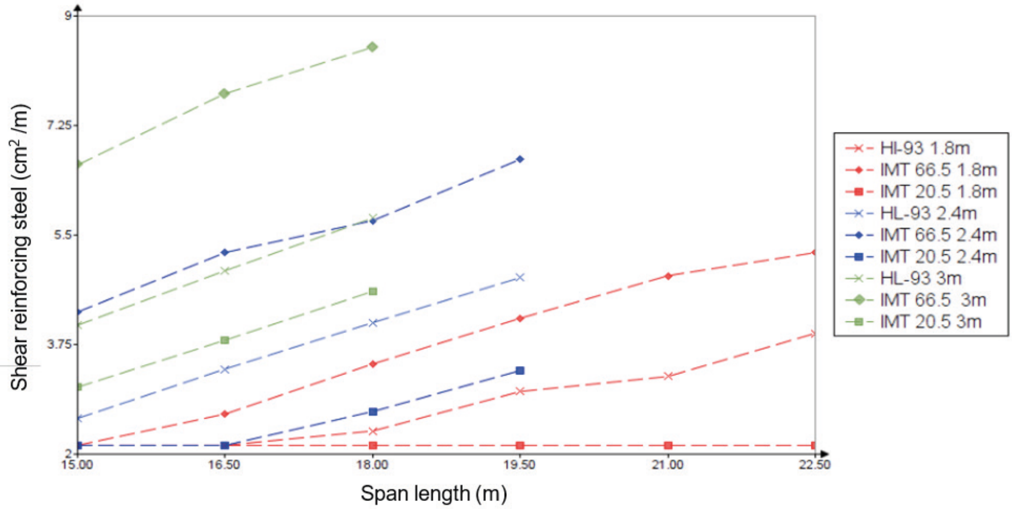

Figure 5.4. Shear reinforcement vs. span length for AASHTO Type II beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

		Ultimate shear due to design loads, ton.			Shear reinforcing steel due to design loads, cm /m^2			Difference between ultimate shear, ton				Difference between shear steel areas, cm /m2			
								HL-93 vs IMT 66.5		HL-93 vs IMT 20.5		HL-93 vs IMT 66.5		HL-93 vs IMT 20.5	
Interval between clearings, m	Beam spacing, m	HL-93	IMT 66.5	IMT 20.5	HL-93	IMT 66.5	IMT 20.5	Diff.	%	Diff.	%	Diff.	%	Diff.	%
15-22.5	1.80	60.36	67.76	49.54	2.80	3.74	2.14	7.40	12.26	10.82	17.93	0.94	33.57	0.66	23.57
15-19.5	2.40	70.51	83.60	60.30	4.01	5.98	3.10	13.09	18.56	10.21	14.48	1.97	49.13	0.91	22.69
15-18	3.00	77.83	96.80	69.60	4.92	7.62	3.83	18.97	24.37	8.23	10.57	2.70	54.88	1.09	22.15

Table 5.2. Ultimate shear and shear reinforcing steel for AASHTO Type II beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

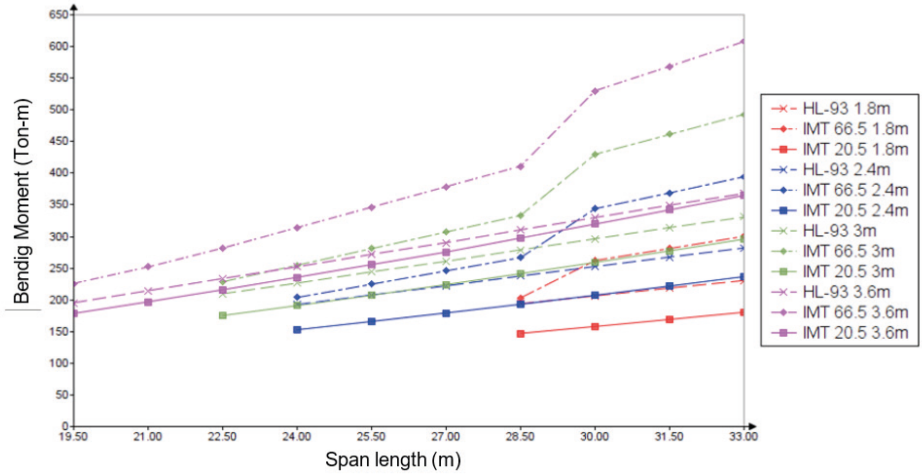

Figure 6.1. Bending moments at center span for AASHTO Type VI beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

		Bending moments at the center of the span with impact due to design loads, ton-m.			Difference between bending moments.			
					HL-93 vs IMT 66.5		HL-93 vs IMT 20.5	
Interval between clearings, m	Beam spacing, m	HL-93	IMT 66.5	IMT 20.5	Difference	%	Difference	%
28.5	1.80	194.05	203.19	147.16	9.14	4.71	46.89	24.16
30-33	1.80	218.52	281.19	169.13	62.67	28.68	49.39	22.60
24-28.5	2.40	215.07	235.18	172.77	20.11	9.35	42.30	19.67
30-33	2.40	267.34	368.98	221.93	101.64	38.02	45.41	16.99
22.5-28.5	3.00	244.05	280.87	207.80	36.82	15.09	36.25	14.85
30-33	3.00	313.75	461.23	277.42	147.48	47.01	36.33	11.58
19.5-28.5	3.60	252.67	315.70	236.57	63.03	24.95	16.10	6.37
30-33	3.60	349.13	568.85	342.15	219.72	62.93	6.98	2.00

Table 6.1 Comparison of bending moments at center span of AASHTO VI beam due to HL-93, IMT 666.5 and IMT-20.5 loads.

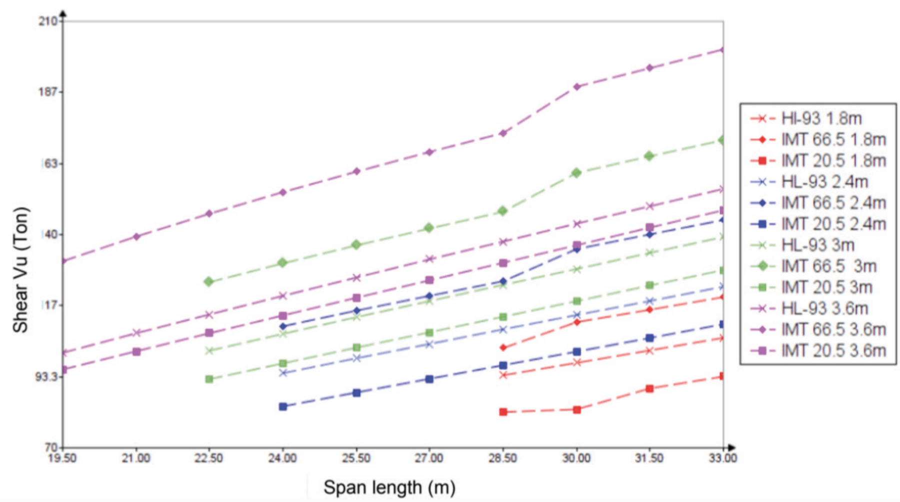

Figure 6.2. Ultimate shear vs span length for AASHTO Type VI beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

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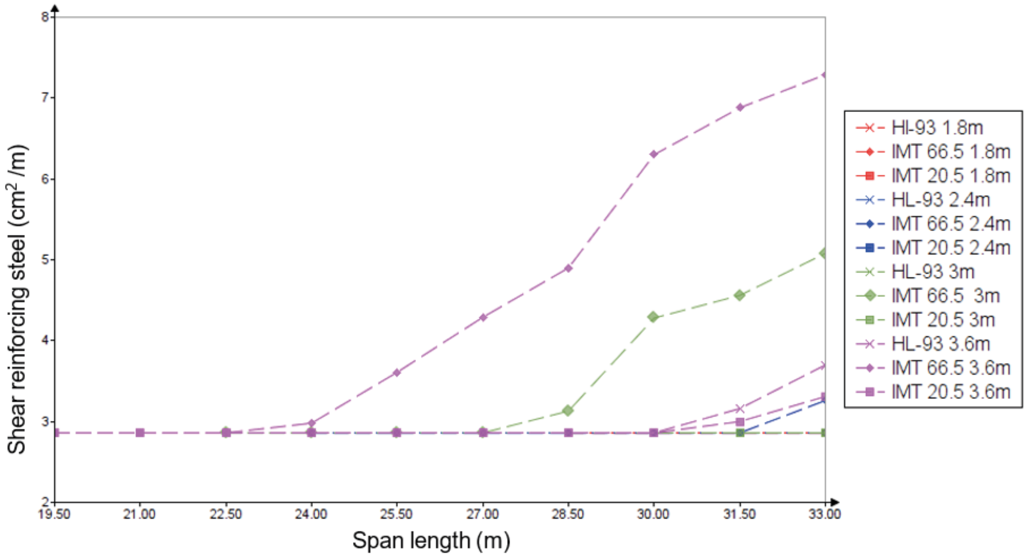

Figure 6.3. Shear reinforcement vs. span length for AASHTO Type VI beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

		Ultimate shear due to design loads, ton.			Shear reinforcement steel due to design loads, cm /m^2			Difference between ultimate shear, ton				Difference between shear steel areas, cm /m2			
								HL-93 vs IMT 66.5		HL-93 vs IMT 20.5		HL-93 vs IMT 66.5		HL-93 vs IMT 20.5	
Interval between clearings, m	Beam spacing, m	HL-93	IMT 66.5	IMT 20.5	HL-93	IMT 66.5	IMT 20.5	Diff.	%	Diff.	%	Diff.	%	Diff.	%
28.5	1.80	93.80	102.75	81.73	2.86	2.86	2.86	8.95	9.54	12.07	12.87	0.00	0.00	0.00	0.00
30-33	1.80	102.00	115.30	88.51	2.86	2.86	2.86	13.30	13.04	13.49	13.23	0.00	0.00	0.00	0.00
24-28.5	2.40	101.72	117.38	90.40	2.86	2.86	2.86	15.66	15.40	11.32	11.13	0.00	0.00	0.00	0.00
30-33	2.40	118.23	140.04	106.08	2.86	2.99	2.86	21.81	18.45	12.15	10.28	0.13	4.55	0.00	0.00
22.5-28.5	3.00	112.78	136.18	102.82	2.86	2.91	2.86	23.40	20.75	9.96	8.83	0.05	1.89	0.00	0.00
30-33	3.00	134.00	165.66	123.27	2.86	4.64	2.86	31.66	23.63	10.73	8.01	1.78	62.24	0.00	0.00
19.5-28.5	3.60	119.71	153.22	113.35	2.86	3.48	2.86	33.51	27.99	6.36	5.31	0.62	21.68	0.00	0.00
30-33	3.60	149.30	194.66	142.26	3.24	6.82	3.05	45.36	30.38	7.04	4.72	3.58	110.49	0.19	5.86

Table 6.2. Ultimate shear and shear reinforcing steel for AASHTO Type VI beam with beam spacings of 6, 8 and 10 ft (1.8m, 2.4m and 3m) due to design loads HL-93, IMT 66.5 and IMT 20.5.

Figure 6.3 shows the comparison of the shear reinforcing steel area for the AASHTO Type VI beam, taking into account HL-93, IMT 66.5 and IMT 20.5 loads.

The data presented in Table 6.2, which are based on Figures 6.2 and 6.3, indicate that the IMT 66.5 load requires 46.35% more steel per shear on average compared to the HL-93 load (Figure 6.3 and Table 6.2).

Bridge design in Mexico combines elements of the AASHTO-LRFD method with traditional SCT practices. Even though efforts are being made to modernize the applied regulations, challenges related to the full implementation of the LRFD persist due to the lack of specific design guidelines. Effective integration of both methods could significantly improve the safety and efficiency of bridge structural design in the country.

CONCLUSIONS

1. It was determined that using the Moment Distribution Factor (MDF) according to the AASHTO-LRFD standard and the SCT IMT 66.5 truck, the same amount of strands required is obtained as when using the HL-93 load for spans ranging from 15m to 28.5m and beam spacing of 1.8m, 2.4m, 3m and 3.6m. However, it was observed that the shear reinforcing steel increases by 15% to 20% when using the SCT IMT 66.5 truck, depending on the beam spacing.

2. By applying the AASHTO-LRFD standard, it was possible to establish that by increasing the ultimate moments due to the HL-93 load by 20% and 25.3% in beams with 3m and 3.6m spacing and spans ranging from 15m to 28.5m, it is possible to obtain the ultimate moments corresponding to the IMT 66.5 truck using the SCT standard with a difference of 2%. If these percentage increases are applied to the ultimate moments under the previously mentioned conditions, the AASHTO-LRFD standard can be used instead of the SCT standard in the design of Type "A" highway bridges.

3. The main difference between the two standards is in the load distribution factors (LDF). In general, the SCT FDC is 15% more conservative than the AASHTO-LRFD FDC when beam spacings exceed 2.4m. This leads to the fact that using the SCT standard, the number of strands and/or the corresponding beam cross-section dimensions increase, resulting in increased cost of materials, labor and equipment.

4. It was noted that the AASHTO-LRFD takes into account additional factors such as geometric properties and stiffness of composite beam and slab sections, which allows for a more optimized design leading to a reduction in materials and a decrease in time and cost of fabrication and erection of structural elements.

5. The increase of overweight vehicles in Mexico presents significant challenges to the effectiveness of both regulations, requiring a reevaluation of design practices. Future research should focus on integrating finite element analysis and exploring alternative beam types to improve the performance and sustainability of bridge designs in Mexico.

RECOMMENDATIONS:

1. Perform a finite element analysis on the superstructure of prestressed concrete bridges in Mexico taking into consideration different spans and girder spacings, and applying the SCT load standards. The purpose is to obtain the moment and shear distribution coefficients, considering not only the spacing between beams, but also other design parameters that go beyond those established in the current AASHTO-LRFD standard for bridge design.

2. To expand on the research conducted in this study, it is suggested to carry out an analysis with box girders, as they are cost-effective in their on-site execution, which saves time and slab construction, since they comply with the walkable width of vehicles (Sennah & Eng, 2020).

3. Finally, it is suggested to investigate "pi" type beams, since they have the advantage of not requiring secondary shear reinforcement when fabricated with ultra-high strength concrete (Foster & Bentz, 2024).

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