Base Pressure (P_B) Corresponding to (V_B) = 160 km/hr.

Superstructure Component	Windward Load MPa	Leeward Load MPa
Trusses, Columns and Arches	0.0024	0.0012
Beams	0.0024	NA
Large Flat Surfaces	0.0019	NA

The total wind loading shall not be taken less than:

- 4.4 N/mm on beam or girder spans.
- 4.4 N/mm in the plane of a windward chord.
- 2.2 N/mm in the plane of a leeward chord on truss and arch components.

- ***Wind Pressure on Superstructure***

Where the wind is not taken as normal to the structure, the base wind pressures (P_B) may be taken from Tables. The skew angle shall be taken as measured from a perpendicular to the longitudinal axis and the transverse and longitudinal pressures shall be applied simultaneously.

Base Pressure (P_B) for Various Angles of Attack and (V_B) = 160 km/hr.

Skew Angle of Wind Deg.	Trusses, Columns and Arches		Girders	
	Lateral Load MPa	Longitudinal Load MPa	Lateral Load MPa	Longitudinal Load MPa
0	0.0036	–	0.0024	–
15	0.0034	0.0006	0.0021	0.0003
30	0.0031	0.0013	0.0020	0.0006
45	0.0023	0.0020	0.0016	0.0008
60	0.0011	0.0024	0.0008	0.0009

- ***Wind Pressure on Substructure***

The transverse and longitudinal forces to be applied directly to the substructure shall be calculated from an assumed base wind pressure of $1.9\text{x}10^{-3}$ MPa. The skewed wind force on the substructure must be resolved into components perpendicular to the end and front elevations of the substructure.

Wind Pressure on Vehicles

When vehicles are present, the design wind pressure shall be applied to both structure and vehicles. Wind pressure on vehicles (WL) shall be represented by an interruptible, moving force of 1.46 N/mm acting normal to, and 1800 mm above, the roadway and shall be transmitted to the structure. This is applicable for load combinations of Strength III, Strength IV and Service I.

When wind on vehicles is not taken as normal to the structure, the components of normal and parallel force applied to the live load may be taken as:

Wind Components on Live Load

Skew Angle of Wind Deg.	Normal Components N/mm	Parallel Components N/mm
0	1.46	–
15	1.28	0.18
30	1.20	0.35
45	0.96	0.47
60	0.50	0.55

Vertical Wind Pressure

A vertical upward wind force of 9.6×10^{-4} MPa times the width of the deck, including parapets and sidewalks, shall be considered to be a longitudinal line load. This force shall be applied only for the Strength III and Service IV limit states which do not involve wind on live load, and only when the direction of wind is taken to be perpendicular to the longitudinal axis of the bridge. This load may govern where overturning of the bridge is investigated.

Uniform Temperature

The design thermal movement associated with a uniform temperature (TU) change may be employed for concrete deck bridges having concrete or steel girders. Table below can be used to calculate thermal deformation effects.

Temperature Ranges

Climate	Steel or Aluminum ˚C	Concrete ˚C	Wood ˚C
Moderate	-18 – 50	-12 – 27	-12 – 24
Cold	-35 – 50	-18 – 27	-18 – 24

The design thermal movement range (Δ_T) shall depend upon the extreme bridge design temperatures as:

$$\Delta_T = \alpha . L(T_{Max.Design} - T_{Min.Design})$$

where:

α: coefficient of thermal expansion (mm/mm/°C).

L: expansion length (mm).

Temperature Gradient

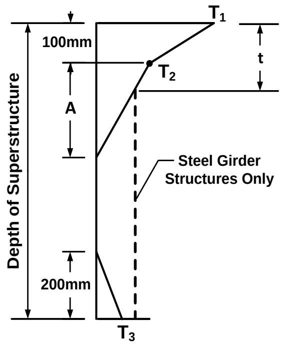
The vertical temperature gradient (TG) in concrete and steel superstructures with concrete decks may be taken as shown in Figure:

Dimension A in Figure shall be taken as:

- $(A = 300\ mm)$ for concrete superstructures that are 400 mm or more.

- ($A =$ the actual depth $-$ 100 mm) for concrete sections shallower than 400 mm.
- ($A = 300\ mm$) for steel superstructures and take ($t =$ the depth of the concrete deck).

Temperature value (T_3) shall be taken as 0°C unless a site-specific study is made to determine an appropriate value, but it shall not exceed 3°C.



Review on Concrete Bridges Design

Herein, AASHTO specifications combine and unify the requirements for design reinforced, prestressed and partially prestressed concrete bridges.

Normal and Structural Lightweight Concrete

- ***Compressive Strength***

The average compressive strength of the cylindrical samples (f_c') at age of 28-days for concrete, must be within:

- $16 < f_c' \leq 70\ MPa$ [structural applications]
- $f_c' \geq 28\ MPa$ [prestressed concrete and decks]

- ***Cement Content***

The sum of Portland cement and other cementitious materials (C) shall be specified as: exceed 475 kg/m^3, except for Class P (HPC) concrete where the sum of Portland cement and other cementitious materials shall be specified not to exceed 593 kg/m^3:

- $C \leq 475\ kg/m^3$ [ordinary concrete]
  $\leq 593\ kg/m^3$ [Class P high performance concrete (HPC)]

- ***Coefficient of Thermal Expansion***

For more precise data, the coefficient of thermal expansion (α) should be determined by laboratory tests. Other else, it may be taken as:

- $\alpha = 10.8\ x\ 10^{-6}$ /°C [normal density concrete]
  $= 9.0\ x\ 10^{-6}$ /°C [low-density concrete]

- ***Modulus of Elasticity***

In the absence of measured data, the modulus of elasticity (E_c) for concretes with unit densities between 1440 and 2500 kg/m^3 and specified compressive strengths (f_c') up to 105 MPa may be taken as:

$$E_c = 0.043 K_1 \Upsilon_c^{\,1.5} \sqrt{f_c'}$$

where:

K_1: correction factor for aggregate source; taken as 1.0 in absent of physical test.
Υ_c: unit density of concrete (kg/m^3)
f_c': specified compressive strength of concrete (MPa)

- $E_c = 4800\sqrt{f_c'}$ [normal density concrete with $\Upsilon_c = 2320\ kg/m^3$]

- ***Poisson's Ratio***

Unless determined by physical tests, Poisson's ratio (ν) may be assumed as 0.2. For components expected to be subject to cracking, the effect of Poisson's ratio may be neglected.

- ***Modulus of Rupture***

Unless determined by physical tests, the modulus of rupture (f_r) in MPa, for specified concrete strengths up to 105 MPa, may be taken as:

- $f_r = 0.52\sqrt{f_c'}$ [normal density concrete with distribution steel design]
  $= 0.63\sqrt{f_c'}$ [normal density concrete with deflection and camber calculations]
  $= 0.97\sqrt{f_c'}$ [normal density concrete with minimum steel case]
  $= 0.45\sqrt{f_c'}$ [all low-density concrete]
  $= 0.52\sqrt{f_c'}$ [sand low-density concrete]

- ***Tensile Strength***

For most regular concretes, the direct tensile strength (f_t) may be estimated as:

- $f_t = 0.62\sqrt{f_c'}$

Reinforcing Steel

- ***Yield Strength***

The reinforcing steel must be deformed and with yield strength (f_y):

- $420 \le f_y \le 520\ MPa$ [design purposes]

Plain steel bars or plain wire may be used for spirals, hoops and wire fabric. Bars with yield strengths less than 420 MPa shall be used only with the approval of the owner.

- ***Modulus of Elasticity***

The modulus of elasticity (E_s) of reinforcing steel can be assumed as 2x10^5 MPa.

Prestressing Steel

The prestressing steel properties must be following one of the:

- Uncoated, stress-relieved or low-relaxation, seven-wire strand.
- Uncoated plain or deformed, high-strength bars.

- ***Yield Strength***

The yield strength of the prestressing steel (f_{py}) as related to its tensile strength (f_{pu}) is specified in Table below:

Properties of Prestressing Strand and Bar

Material	Grade or Type	Diameter (∅) mm	Tensile Strength (f_{pu}) MPa	Yield Strength (f_{py}) MPa
Strand	Grade 1725 [250]	6.35 – 15.24	1725	$0.85f_{pu}$
	Grade 1860 [270]	9.53 – 15.24	1860	$0.90f_{pu}$*
Bar	Type 1, Plain	19 – 35	1035	$0.85f_{pu}$
	Type 2, Deformed	16 – 35	1035	$0.80f_{pu}$

*[low-relaxation strand]

- ***Modulus of Elasticity***

If more precise data are not available, the modulus of elasticity for prestressing (E_p) steels, may be taken as:

- $E_p = 1.97x10^5\ MPa$ [strands]
  $= 2.07x10^5\ MPa$ [bars]

Deflection

For many reasons, structurally and aesthetically, vertical deflection (Δ) must be controlled. AASHTO specifications focus on two stages of deflection limitations:

- ***Construction Time***

During construction work, elastic deflection is produced by labor and equipment as well dead load of members.

- $L/180 \leq 13\ mm$ [span length (L) ≤ 3000 mm]
- $L/240 \leq 20\ mm$ [span length (L) > 3000 mm]

- ***Service Life***

Along the bridge service life, dead and live load as well dynamic allowance produce corresponding deflections. So, these deflections need to be controlled. For steel, aluminum and/or concrete bridges, the value of deflection (Δ) must be within:

- $\Delta \leq L/800$ [vehicular load (general)]

$\leq L/1000$ [vehicular and/or pedestrian loads]
$\leq L/300$ [vehicular load on cantilever arm]
$\leq L/375$ [vehicular and pedestrian loads on cantilever arm]

To control vertical deflection at any stage of bridge life, a minimum depth value is must be provided. Table below determine the minimum depth of superstructure to control deflection.

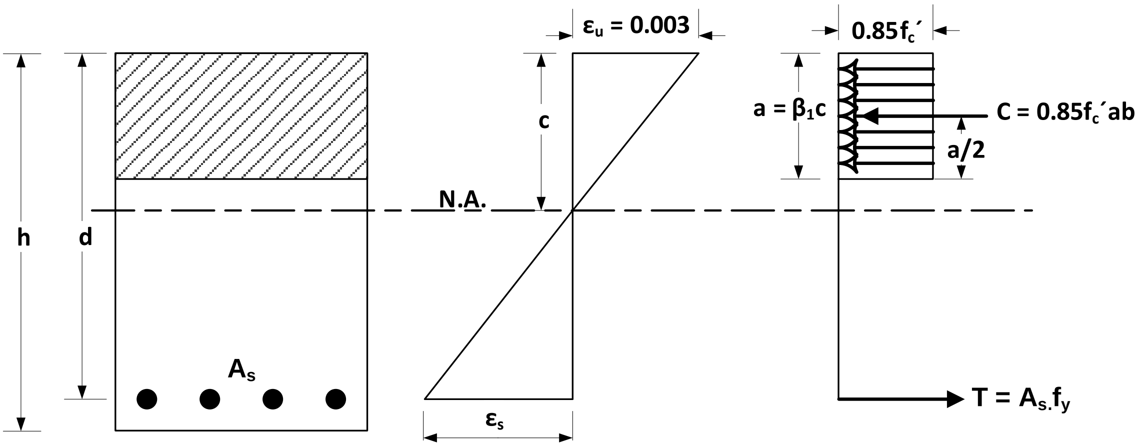
Table 2.5.2.6.3-1: Traditional Minimum Depths for Constant Depth Superstructures

Superstructure		Minimum Depth (Including Deck) mm	
Material	**Type**	**Simple Spans**	**Continuous Spans**
Reinforced Concrete	Slabs	$1.2(S+3000)/30$	$(S+3000)/30 \geq 165$
	T-Beams	$0.070L$	$0.065L$
	Box Beams	$0.060L$	$0.055L$
	Pedestrian Structure Beams	$0.035L$	$0.033L$
Prestressed Concrete	Slabs	$0.030L \geq 165$	$0.027L \geq 165$
	Precast I-Beams	$0.045L$	$0.040L$
	CIP Box Beams	$0.045L$	$0.040L$
	Pedestrian Structure Beams	$0.033L$	$0.030L$
	Adjacent Box Beams	$0.030L$	$0.025L$
Steel	Overall Depth of Composite I-Beam	$0.040L$	$0.032L$
	Portion Depth of Composite I-Beam	$0.033L$	$0.027L$
	Trusses	$0.100L$	$0.100L$

- When variable depth members are used, values may be adjusted to account for changes in relative stiffness of positive and negative moment sections.
- Slabs are basically with main reinforcement parallel to traffic.
- Symbol (S) refers to the span (center/center of supports) length of nonprestressed slab.
- Symbol (L) refers to the span (center/center of supports) length in general.
- Acronym (CIP) refers to Cast-In-Place concrete.

Rectangular Stress Distribution

The natural relationship between concrete stress and strain may be considered satisfied by an equivalent rectangular concrete compressive stress block (Whitney block) of $(0.85f_c')$ over a zone bounded by the edges of the cross-section and a straight line located parallel to the neutral axis at the distance $(a = \beta_1 c)$ from the extreme compression fiber. The distance (c) shall be measured perpendicular to the neutral axis.



Strain Distribution and Net Tensile Strain

Value of (β_1) for Equivalent Rectangular Concrete Stress Distribution

Compressive Strength (f'_c) MPa	(β_1)
$16 < f'_c \le 28$	0.85
$28 < f'_c < 55$	$0.85 - 0.05(f'_c - 28)/7$
$f'_c \ge 55$	0.65

Flexural Resistance

The factored flexure resistance (M_r) and nominal flexural resistance (M_n) may be taken as:

- $M_r = \phi M_n$
- $M_n = A_{ps}.f_{ps}\left(d_{ps} - \frac{a}{2}\right) + A_s.f_s\left(d_s - \frac{a}{2}\right) - A'_s.f'_s\left(d'_s - \frac{a}{2}\right)$ [rectangular section behavior]

  $= A_{ps}.f_{ps}\left(d_{ps} - \frac{a}{2}\right) + A_s.f_s\left(d_s - \frac{a}{2}\right) - A'_s.f'_s\left(d'_s - \frac{a}{2}\right) + 0.85f'_c(b_f - b_w)h_f\left(\frac{a}{2} - \frac{h_f}{2}\right)$

  [T-section behavior]

where:

A_{ps}, A_s, A'_s: area of prestressing, tensile and compressive steel (mm^2)

f_{ps}, f_s, f'_s: stress at prestressing, tensile and compressive steel (MPa)

d_{ps}, d_s, d'_s: effective depth of prestressing, tensile and compressive steel (mm)

f'_c: compressive concrete strength of monolithic section (MPa)

b_f, b_w: width of flange and web of monolithic section (mm)

h_f, a: depth of concrete flange and Whitney block (mm)

Shear Resistance

The factored shear resistance (V_r) and nominal shear resistance (V_n) may be taken as:

- $V_r = \phi V_n$
- $V_n = V_c + V_s + V_p$ [except slabs, footings and culverts]

  $\le 0.25f'_c.b_v.d_v + V_p$

where:

V_c: shear resistance of the concrete section (N)

V_s: shear resistance of steel (stirrups) in the section (N)

V_p: component of prestressing force in direction of the shear force (N)

b_v: effective web width (mm)

d_v: effective shear depth (mm)

Reinforcement Details

Herein, some of ASSHTO specifications for clear cover and spacing of reinforcement.

Concrete Cover

Minimum cover is necessary for durability and prevention of splitting due to bond stresses and to provide for placing tolerance.

Cover for Unprotected Main Reinforcing Steel

Situation		Clear Cover (c_c) mm
Direct exposure to salt water		100
Cast against earth		75
Coastal		75
Exposure to deicing salts		60
Deck surfaces subject to tire stud or chain wear		60
Exterior other than above		50
Interior other than above	$Ø_b \leq 36\ mm$	40
	$Ø_b = 43\ mm$ and $Ø_b = 57\ mm$	50
Bottom of CIP Slabs	$Ø_b \leq 36\ mm$	25
	$Ø_b = 43\ mm$ and $Ø_b = 57\ mm$	50
Precast soffit form panels		20
Precast Reinforced Piles	Noncorrosive environments	50
	Corrosive environments	75
Precast Prestressed Piles		50
CIP Piles	Noncorrosive environments	50
	Corrosive environments (General, Protected)	75
	Shells	50
	Auger-cast, tremie concrete or slurry construction	75

- Minimum cover to main bars, including bars protected by epoxy coating, shall be 25 mm.
- Cover to ties and stirrups may be 12 mm less than the values specified in Table for main bars but shall not be less than 25 mm.

Minimum Spacing of Reinforcing Bars

- ***Cast-in-Place Concrete***
  - $s_{min} = 1.5Ø_b \geq 1.5d_{ag} \geq 38\ mm$

- ***Precast Concrete***
  - $s_{min} = Ø_b \geq 1.33d_{ag} \geq 25\ mm$

- ***Multilayers***

Except in decks where parallel reinforcing is placed in two or more layers, with clear distance between layers not exceeding 150 mm

  - $s_{min} = 25\ mm \geq Ø_b$

Maximum Spacing of Reinforcing Bars

Unless otherwise specified, the spacing of the reinforcement in walls and slabs shall be:

- $s_{max} = 1.5h \leq 450\ mm$
  $= 3h \leq 450\ mm$ [shrinkage and temperature reinforcement]

Minimum Spacing of Prestressing Steel

- $s_{min} = 1.33d_{ag}$ [pretensioning and post-tensioning methods]
  $\geq Tablulated\ below$ [pretensioning method]
  ≥ 38 mm [post-tensioning method]

Minimum Spacing of Tendons of Pretensioning Method (c/c)

Strand Size ($Ø_p$) mm	Spacing (s_{min}) mm
15.24	51
14.29	
12.70	44
11.11	
9.53	38

Maximum Spacing of Prestressing Steel in Slabs

- $s_{max} = 1.5h_d \leq 450\ mm$ [pretensioning strands]
  $\leq 4h_d$ [post-tensioning tendons, c/c]

Maximum Spacing of Shear (Transverse) Steel

- $v_u = V_u/\phi b_v.d_v$ [reinforced concrete section]
  $= |V_u - \phi V_p|/\phi b_v.d_v$ [prestressed concrete section]
- $s_{max} = 0.8d_v \leq 600\ mm$ [$v_u < 0.125f_c'$]
  $= 0.4d_v \leq 300\ mm$ [$v_u \geq 0.125f_c'$]