4. Construction Materials Properties

4.1. Concrete

Two types of structural concrete are used in bridges construction: normal weight type and lightweight type. This classification is related to the unit weight of concrete (Υ_c). The main concrete properties are demonstrated below.

4.1.1. Compressive Strength

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

- $f_c' \geq 17$ MPa [structural applications]
  ≥ 28 MPa [prestressed concrete and decks]
  ≤ 69 MPa [beyond, tests and allowance are essential]

4.1.2. Cement and Water Content

The sum of Portland cement and other cementitious materials (CM) as well as the water-cement ratio (W/CM) shall be specified as following:

- $CM \leq 475\ \text{kg/m}^3$ [ordinary concrete]
  $\leq 593\ \text{kg/m}^3$ [high performance concrete (HPC)]
- $W/CM \leq 0.45$

4.1.3. 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 weight concrete]
  $= 9.0\ x\ 10^{-6}$ /°C [lightweight concrete]

4.1.4. Modulus of Elasticity

In the absence of measured data, the modulus of elasticity (E_c) for normal-weight concrete with design compressive strengths (f_c') up to (105 MPa) and lightweight concrete with (up to 69 MPa), with unit weight (Υ_c) between (14.4 and 25.6 kN/m^3), may be taken as:

- $E_c = 43 K_1 {\Upsilon_c}^{1.5} \sqrt{f_c'}$ [normal weight and lightweight concrete]

For normal weight concrete with ($\Upsilon_c = 23.2\ \text{kN/m}^3$) and ($f_c' \leq 69$ MPa), (E_c) can be taken as:

- $E_c = 4800\sqrt{f_c'}$

where:

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

4.1.5. Poisson's Ratio

Unless determined by physical tests, Poisson's ratio (ν) may be assumed as (0.2) for normal weight concrete with $(f_c' \leq 105\ \text{MPa})$ and lightweight concrete with $(f_c' \leq 69\ \text{MPa})$. While for components expected to be subject to cracking, the effect of (ν) may be neglected.

4.1.6. Modulus of Rupture

Unless determined by physical tests, the modulus of rupture (f_r) for normal-weight concrete with specified $(f_c' \leq 105\ \text{MPa})$ and lightweight concrete with $(f_c' \leq 69\ \text{MPa})$, may be taken as:

- $f_r = 0.62\lambda\sqrt{f_c'}$

where:

λ: concrete density modification factor; taken as (1.0) for normal-weight concrete.

4.1.7. Tensile Strength

For normal-weight concrete with design $(f_c' \leq 69\ \text{MPa})$, the direct tensile strength (f_t) may be estimated as:

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

4.1.8. Concrete Density Modification Factor

The concrete density modification factor (λ) shall be determined with respect to the concrete splitting tensile strength (f_{ct}) as:

- $\lambda = 0.75$ $\quad [\Upsilon_c \leq 16\ \text{kN/m}^3]$
  $= 1.79 f_{ct}/\sqrt{f_c'} \leq 1.0$ $\quad [f_{ct} \text{ is specified}]$
  $= \Upsilon_c/21.33 \leq 1.0$ $\quad [f_{ct} \text{ is not specified}]$
  $= 1.0$ $\quad [\Upsilon_c \geq 21.6\ \text{kN/m}^3]$

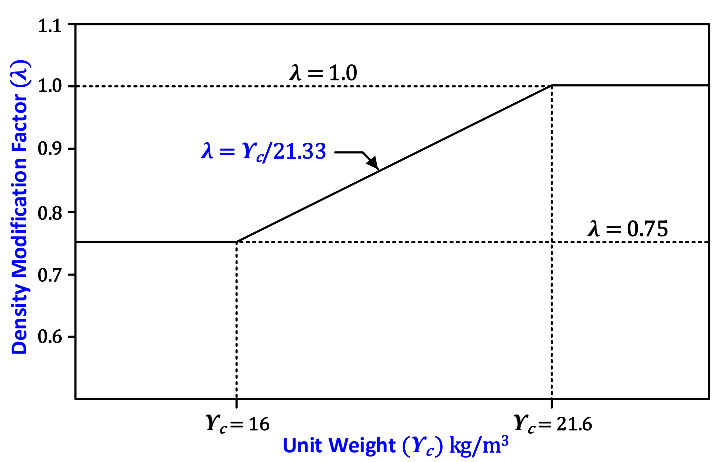

Figure 4-1: Illustration of Concrete Density Modification Factor as a Function of Unit Weight [AASHTO LRFD Figure C5.5.4.2-1 with Unit Conversion]

Three types of steel are used in bridges construction: reinforcing steel, prestressing steel, and steel sections. The main properties of each steel type are demonstrated below.

4.2. Reinforcing Steel

The reinforcing steel must be deformed bars with diameter (Ø) in the range ($12 – 57$ mm). However, plain steel bars or plain wire may be used for spirals, hoops, and wire fabric but not for the main reinforcement.

4.2.1. Tensile Strength

The yield strength of the reinforcing steel (f_y) shall be in the range:

- $520 \leq f_y \leq 690$ MPa

Bars with yield strength ($f_y \leq 420$ MPa) shall be used only with the approval of the owner.

The tensile (ultimate) strength of the reinforcing steel (f_u) shall be considered to achieve the ductility for the design section, so that:

- $f_u \geq 1.25 f_y$

4.2.2. Modulus of Elasticity

The modulus of elasticity for reinforcing steel (E_s) shall be assumed as:

- $E_s = 200x10^3$ MPa [$f_y \leq 690$ MPa]

4.3. Prestressing Steel

The prestressing steel properties must follow one of the:

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

4.3.1. Tensile Strength

The yield strength of the prestressing steel (f_{py}) as related to its tensile strength (f_{pu}) is specified in Table 4.1 below:

Table 4.1: Properties of Prestressing Strand and Bar [AASHTO LRFD Table 5.4.4.1-1]

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

4.3.2. Modulus of Elasticity

If more precise data are not available, the modulus of elasticity for prestressing steel (E_{ps}), may be taken as:

- $E_{ps} = 197x10^3$ MPa [strands]
  $= 207x10^3$ MPa [bars]

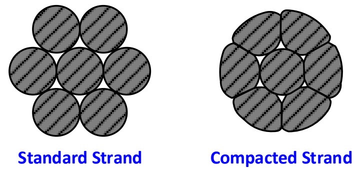

Figure 4.2: Cross Section of Typical Prestressing Strands

4.4. Steel Sections

Steels sections used for structural construction shall conform to the requirements.

4.4.1. Tensile Strength

The specified yield strength (F_y), the specified minimum ultimate or tensile strength (F_u), plate thickness (t) and shapes produced with the type of structural steel are listed in Table 4.2.

Table 4.2: Minimum Mechanical Properties of Structural Steel [AASHTO LRFD Table 6.4.1-1]

Grade	Yield Strength (F_y) MPa	Tensile Strength (F_u) MPa	Plate Thickness (t) mm	Shapes
250	250	400	- 100	All Groups
345	345	450	- 100	All Groups
345S	345	450	N/A	All Groups
345W	345	485	- 100	All Groups
HPS 345W	345	485	- 100	N/A
HPS 485W	485	585	- 100	N/A
HPS 690W	620	690	62.5 - 100	N/A

4.4.2. Modulus of Elasticity

The modulus of elasticity for structural steel sections (E_s) shall be assumed as:

- $E_s = 200x10^3$ MPa

4.4.3. Coefficient of Thermal Expansion

The thermal expansion coefficient (α_s) of structural steel sections may be taken as:

- $\alpha_s = 11.7\text{x}10^{-6}/°\text{C}$

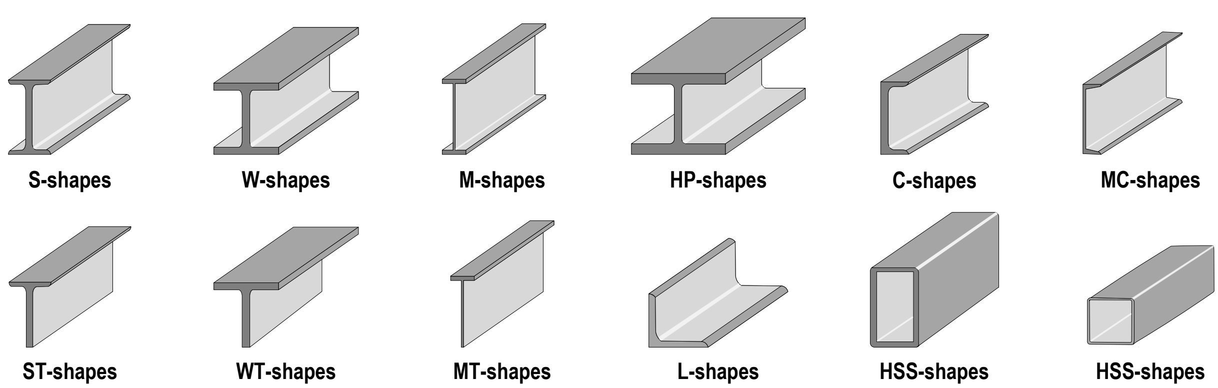

Figure 4-3: Typical Rolled Steel Sections