Limit State for Superstructure Design and Check

For Strength I, Service I and Service III load combinations with vertical load on the bridge, the effect load equation becomes:

- For the strength I limit state:

$$Q_u = \eta.[1.25DC + 1.50DW + 1.75(LL + IM)]$$

By the same way, moment and shear shall be:

$$M_u = \eta.[1.25M_{DC} + 1.50M_{DW} + 1.75M_{LL+IM}]$$

$$V_u = \eta.[1.25V_{DC} + 1.50V_{DW} + 1.75V_{LL+IM}]$$

- For the service I limit state:

$$Q = DC + DW + (LL + IM)$$

- For the service III limit state:

$$Q = DC + DW + 0.80(LL + IM)$$

Resistance Factors

The strength limit state issues are considered for strength and stability. Factored resistance shall be the product of nominal resistance determined according to AASHTO specifications.

$$R_r = \phi R_n \geq Q_u$$

where:

R_r: factored resistance

R_n: nominal resistance

ϕ: resistance factor

Q_u: total factored load

The values of resistance factor (ϕ) shall be taken as:

- For the strength limit state:
  - $\phi = 0.90$ [tension-controlled reinforced concrete sections]
    $= 1.00$ [tension-controlled prestressed concrete sections]
    $= 0.90$ [shear and torsion normal weight concrete sections]
    $= 0.90$ [shear and torsion normal weight concrete sections]
    $= 0.80$ [shear and torsion lightweight concrete sections]
    $= 0.70$ [bearing on concrete]
    $= 0.70$ [compression in strut and tie models]
    $= 0.75$ [compression-controlled sections with spirals or ties]
    $= 0.80$ [compression in anchorage zones normal weight concrete]
    $= 0.65$ [compression in anchorage zones lightweight concrete]
- For all other limit states:
  - $\phi = 1.00$

Design Loads on Bridge

Briefly distributions of loads on bridge superstructure can be summarized as:

- Vertical loads: dead, live and dynamic.
- Longitudinal loads: wind, earthquake, braking, friction and thermal.
- Transversal: wind, earthquake, centrifugal and shock.

Dead Load

The total dead load on the section contains the weights of all structural components and nonstructural attachments (DC) as well the weight of wearing surfaces and utilities (DW). The Table 3.5.1-1: shall be used to calculate dead loads.

The unit weight of reinforced concrete is generally taken as 0.8 kN/m^3 greater than the unit weight of plain concrete. So, in the absence of more precise information, take the specific weight of concrete (Υ_c) = 24 kN/m^3.

Table 3.5.1-1: Unit Weights of Materials

Material		Unit Weight (γ) KN/m^3
Aluminum Alloys		28
Bituminous Wearing Surface		22.5
Cast Iron		72
Cinder Filling		9.6
Compacted Sand, Silt or Clay		19.25
Concrete	Lightweight	17.75 – 19.25
	Normal Weight with $f'_c \leq 35\ MPa$	23.2
	Normal Weight with $35 < f'_c \leq 105\ MPa$	$22.4 + 0.023f'_c$
Loose Sand, Silt or Gravel		16
Soft Clay		16
Rolled Gravel, Macadam or Ballast		22.5
Steel		78.5
Stone Masonry		27.25
Wood	Hard	9.6
	Soft	8
Water	Fresh	10
	Salt	10.25
Item		**Weight / Unit Length KN/m**
Transit Rails, Tires and Fastening / Track		3

Determination of Maximum Moment and Shear for Dead Load and Lane Load

Both maximum bending moment and maximum shear force due to dead loads and other static loads on the section depend on:

- w_{DL}: continuous static load on the section [w_{DC}, w_{DW} and w_{Ln}]
- L: effective length of span

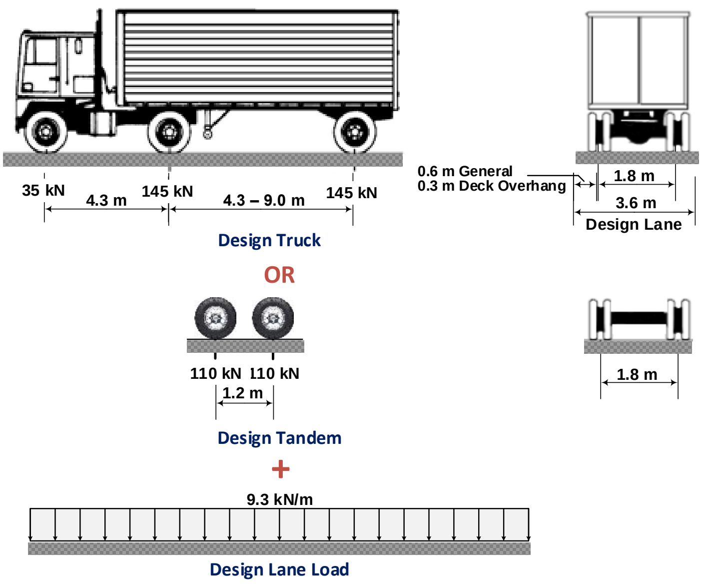
Maximum Bending Moment and Shear Force Due to Continuous Static Loads

Type of Span	Effective Length (L) mm	Bending Moment (M_{DL}) N.mm	Shear Force (V_{DL}) N
Simple	center/center of supports	$+ w_{DL}L^2/8$	$w_{DL}L/2$
Continuous	center/center of supports	$+ w_{DL}L^2/24$ $- w_{DL}L^2/12$	$w_{DL}L/2$
Cantilever	center of support/free end	$- w_{DL}L^2/2$	$w_{DL}L$

Vehicular Live Load

The vehicular live loading on the roadways of bridges or incidental structures is defined by AASHTO specifications, designated HL-93, shall consist of a combination of the:

- **Design Truck**: The weights and spacings of axles and wheels for the design truck is as specified below. To produce extreme force effects, the rare axles spacing shall be varied between 4300 and 9000 mm.
- **Design Tandem**: The design tandem shall consist of a pair of 110000 N axles spaced 1200 mm apart. The transverse spacing of wheels shall be taken as 1800 mm.
- **Design Lane Load**: Uniformly distributed load of 9.3 N/mm in the longitudinal direction. Transversely, the design lane load is assumed to be uniformly distributed over a width of 3000 mm.



Combination of Vehicular Live Load

Determine Maximum Moment and Shear for Moving Load on Simple Spans

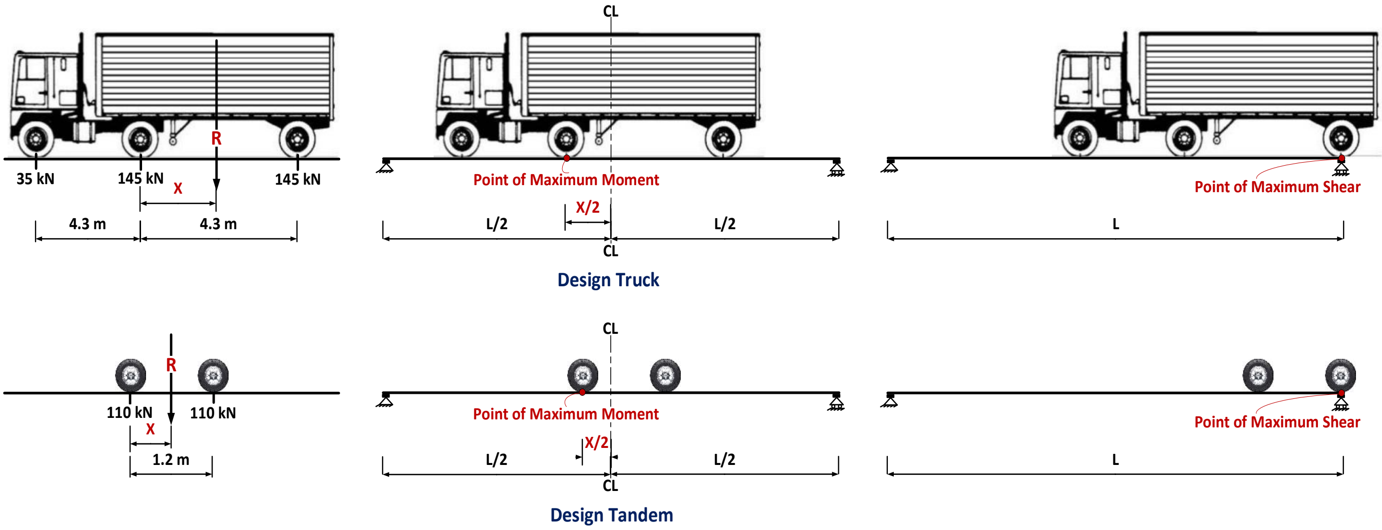
The maximum moment or shear does not depend on the moving loads magnitudes only. However, the position of the moving load is more considerable. The critical position of the moving load on the bridge need to be determined by influence lines application.

So, the maximum moment caused by a moving load can be computed instantaneously when the center of the simple span is at the middle distance between the resultant (R) of the moving load and its nearest axle load. To find the maximum bending moment of moving load as truck (M_{Tr}) or tandem (M_{Ta}), follow that:

- Find the distance (X) between the resultant (R) of moving load and its nearest axle load.
- Then, neglect (R) and assume its nearest axle load lies at point (o) of distance $(X/2)$ from the center of the span.
- Determine the positions of the other front and rear axles of the moving load on the span.
- Compute the supports reactions, then make a cut at point (o) to find the moment therein.

The maximum shear force (V_{Tr}) or (V_{Ta}) can be computed instantaneously on a support when the entire moving load is inside the span and its rear axle is closest to that support.

- If $L \geq 12\ m$ →HS–93 design Truck governs over Tandem for Moment
- If $L \geq 8.5\ m$ →HS–93 design Truck governs over Tandem for Shear



Maximum Moment and Shear Locations under Moving Load on Simple Spans

Dynamic Load Allowance

It is clear that when a moving vehicle across a bridge at a specific speed, stresses are produced greater than ones when the vehicle remains static on the bridge.

The static effects of the design truck or tandem, other than centrifugal and braking forces on superstructure and other bridge portions above the ground level shall be increased by the percentage specified by AASHTO for dynamic load allowance (IM).

The (IM) factor to be applied to the static load shall be taken as: $(1 + IM)$.

In contrast, the (IM) shall not be applied to pedestrian loads or to the design lane load.

Dynamic Load Allowance

Component		Dynamic Load Allowance (IM)
Deck Joints	All Limit States	75%
All Other Components	Fatigue and Fracture Limit State	15%
	All Other Limit States	33%

The dynamic load allowance for culverts and other buried structures, shall be taken as:

$$IM = 33\%(1.0 - 4.1x10^{-4}D_E) \geq 0$$

where D_E: minimum depth of earth cover above the structure (mm)

Tire Contact Area

The area load applies only to the design truck and tandem. For other design vehicles, the tire contact area should be determined by the engineer.

As a guideline for other truck loads, the tire area in mm^2 may be calculated from the following dimensions:

$$Tire\ width = P/142$$
$$Tire\ length = 165\gamma(1 + IM)$$

where:

P: design wheel load (N)

γ: load factor

IM: dynamic load allowance factor

AASHTO specifications state that, tire width is 510 mm and whose length is 250 mm.

Multiple Presence of Live Load

The multiple presence factor (m) is needed to investigate the position of vehicular Live Load, thereby, the design lane width (3600 mm) is greater than the truck width (3000 mm). So, the (m) factor is depending on number of loaded lanes (N_L) on the roadway of the bridge.

The (m) factor to be applied to the vehicular Live load shall be taken as: $m(Q_{Mo} + IM)$.

Possible future changes in the physical or functional clear roadway width of the bridge should be considered during determination of lanes. Roadway widths (6000 – 7200 mm) shall have two design lanes, each equal to one-half the roadway width. Thus, lanes number (N_L) is:

- $N_L = 1$ $\quad$ $[3000 \leq \text{w} < 6000 \text{ mm}]$
  $= 2$ $\quad$ $[6000 \leq w \leq 7200 \text{ mm}]$
  $= INT(w/3600)$ $\quad$ $[w > 7200 \text{ mm}]$
- $w = W - 2(W_{tb}) - 2(W_{ed})$

where:

w: the clear roadway width in mm between curbs and/or barriers

W: overall bridge width (mm)

W_{tb}: width of curbs and/or barriers

W_{ed}: distance between the inside face of curb and the centerline of the truck exterior wheel.

Table 3.6.1.1.2-1: Multiple Presence Factor

Number of Loaded Lanes (N_L)	Multiple Presence Factor (m)
1	1.20
2	1.00
3	0.85
> 3	0.65

Braking Force

Based on energy principles, and assuming uniform deceleration, the braking force (BR) determined as a fraction (b) of vehicle weight is:

$$b = v^2/2ga$$

$$BR = b.W$$

where v: highway design speed.

a: braking length.

g: gravitational acceleration (9.807 m^2/s).

W: total weight of truck or tandem.

Calculations for a horizontal force that will act for a period of about 10 seconds, using a speed of 90 km/hr. (25 m/sec.) and a braking length of 122 m yield b = 0.26. Therefore, AASHTO specifications state the braking force shall be taken as the greater of:

- 0.25 of the:
  - axle weights of the design truck.
  - axle weights of the design tandem
- 0.05 of the:
  - (axle weights of the design truck + lane load)
  - (axle weights of the design tandem + lane load)

The braking forces shall be assumed to act horizontally at a distance of 1800 mm above the roadway surface. All design lanes shall be simultaneously loaded likely to become one-directional in the future to cause extreme force effects. Also, the multiple presence factors (m) must apply.

Centrifugal Force

In the curved bridges, for the purpose of computing the radial force or the overturning effect on wheel loads, the centrifugal force (CE) on live load shall be taken as the product of the axle weights of the design truck or tandem and the factor (c), taken as:

$$c = f.v^2/gR$$

$$CE = c.W$$

where:

f: 1.0 for fatigue load combinations and 4/3 for all others than fatigue.

v: highway design speed.
g: gravitational acceleration.
R: radius of curvature of traffic lane.
W: total weight of truck or tandem.

The braking forces shall be assumed to act horizontally at a distance of 1800 mm above the roadway surface and the multiple presence factors (m) must apply.

Pedestrian Load

For bridges carrying vehicles and pedestrians, all sidewalks wider than 600 mm must be designed for pedestrian load (PL) of 3.6×10^{-3} MPa and considered simultaneously with the vehicular design live load. Whilst, bridges for only pedestrian and/or bicycle traffic shall be designed for a live load of 4.1×10^{-3} MPa.

Live Load Surcharge

A live load surcharge (LS) shall be applied where vehicular load is expected to act on the surface of the backfill within a distance equal to one-half the wall height behind the back face of the wall. The increase in horizontal pressure due to live load surcharge may be estimated as:

$$\Delta_P = k.\gamma_s.g.h_{eq} \times 10^{-9}$$

where Δ_P: constant horizontal earth pressure due to live load surcharge (MPa).
k: coefficient of lateral earth pressure.
γ_s: total density of soil (kg/m^3).
g: gravitational acceleration (m/s^2).
h_{eq}: equivalent height of soil for vehicular load (mm).

To simplify calculation process, AASHTO specifications facilitate to use equivalent heights of soil (h_{eq}) for highway loadings on abutments and retaining walls may be taken:

Equivalent Height of Soil for Vehicular Loading on Abutments

Abutment Height (H) mm	Equivalent Soil Height (h_{eq}) mm
1500	1200
3000	900
≥ 6000	600

Vehicular Collision Force

Unless whole protection is assurance, abutments and piers located within a distance of 9000 mm to the edge of roadway, or within a distance of $15\text{x}10^3$ mm to the centerline of a railway track, shall be designed for an equivalent static force (CT) of $1.8\text{x}10^6$ N, which is assumed to act in any direction in a horizontal plane, at a distance of 1200 mm above ground.

The AASHTO specifications recommends presence of one of the following for structures which are protected by:

- An embankment.
- A structurally independent, crashworthy ground mounted 1370 mm high barrier, located within 3000 mm from the component being protected.
- A 1070 mm high barrier located at more than 3000 mm from the component being protected.

Wind Load

Wind load (WL) is assumed to be uniformly distributed on the area (including floor system and railing) exposed to the wind.

Pressures specified herein shall be assumed to be caused by a base design wind velocity, (V_B). For bridges or parts of bridges more than 10^4 mm above low ground or water level, the design wind velocity (V_{DZ}) should be adjusted according to:

$$V_{DZ} = 2.5V_{\circ}(V_{10}/V_B)\ln(Z/Z_{\circ})$$

where:

V_{DZ}: design wind velocity (km/hr.) at design elevation Z.
$V_{\circ}$: friction velocity, a meteorological wind characteristic.
V_{10}: wind velocity (km/hr.) at 10^4 mm above low ground or design water level.
V_B: base wind velocity (160 km/hr.) at 10^4 mm height.
Z: height of structure at which wind loads are being calculated (> 10^4 mm).
$Z_{\circ}$: friction length of upstream fetch, a meteorological wind characteristic.

Values of ($V_{\circ}$) and ($Z_{\circ}$) for Various Upstream Surface Conditions

Condition	Open Country	Suburban	City
($V_{\circ}$) km/hr.	13.2	17.6	19.3
($Z_{\circ}$) mm	70	1000	2500

Wind Pressure on Structures

In the absence of more precise data, design wind pressure on structure (WS) may be determined as:

$$P_D = P_B(V_{DZ}/V_B)^2$$

where:

P_D: base wind pressure (MPa).
V_{DZ}: design wind velocity (km/hr.) at design elevation Z.
V_B: base wind velocity (160 km/hr.) at 10^4 mm height.