1

LRFD Method of Bridge Design

In load and resistance factor design (LRFD), bridges are designed for specific limit states that consider various loads and resistance. These limit states include strength, extreme event, service, and fatigue, and are defined in the first section of this chapter. Subsequent sections cover the following load and resistance factors in more detail:

- Load combinations and load factors
- Strength limit states for superstructure design
- Resistance factors for strength limits
- Design live loads
- Number of design lanes
- Multiple presence of live loads
- Dynamic load allowances
- Live load distribution factors
- Load combinations for the Strength I Limit State
- Simple beam moments and shears carrying moving concentrated loads

Limit States

The following load combinations are defined in AASHTO. Bridges are designed for these limit states with consideration for the load and resistance factors detailed in later sections of this chapter.

A Art. 3.4.1, 1.3.2*

- **Strength I**: Basic load combination related to the normal vehicular use of the bridge without wind
- **Strength II**: Load combination relating to the use of the bridge by owner-specified special design vehicles and/or evaluation permit vehicles, without wind

* The article numbers in the *2010 Interim Revisions* to the *AASHTO Bridge Design Specifications*, fifth edition, 2010 are by the letter A if specifications and letter C or Comm if commentary.

- **Strength III**: Load combination relating to the bridge exposed to wind velocity exceeding 55 mph without live loads
- **Strength IV**: Load combination relating to very high dead load to live load force effect ratios exceeding about 7.0 (e.g., for spans greater than 250 ft)
- **Strength V**: Load combination relating to normal vehicular use of the bridge with wind velocity of 55 mph
- **Extreme Event I**: Load combinations including earthquake
- **Extreme Event II**: Load combinations relating to ice load or collisions by vessels and vehicles
- **Service I**: Load combination relating to the normal operational use of the bridge with 55 mph wind. Also used for live load deflection control

Art. 2.5.2.6.2

- **Service II**: Load combination intended to control yielding of the steel structures and slip of slip-critical connections due to vehicular live load
- **Service III**: Load combination relating only to tension in prestressed concrete structures with the objective of crack control
- **Fatigue I**: Fatigue and fracture load combination related to infinite load-induced fatigue life
- **Fatigue II**: Fatigue and fracture load combination related to finite load-induced fatigue life

The following terms are defined for limit states:

γ_i = Load factor: a statistically based multiplier applied to force effects

ϕ = Resistance factor: a statistically based multiplier applied to nominal resistance, as specified in AASHTO Specification Sections 5–8, and 10–12

η_i = Load modifier: a factor relating to ductility, redundancy, and operational importance

η_D = A factor relating to ductility, as specified in AASHTO Article 1.3.3

η_R = A factor relating to redundancy as specified in AASHTO Article 1.3.4

η_I = A factor relating to operational importance as specified in AASHTO Article 1.3.5

Q_i = Force effect

R_n = Nominal resistance

R_r = Factored resistance: (ϕR_n)

Effects of loads must be less than or equal to the resistance of a member (or its components), or $\eta\gamma Q \leq \Phi R_n = R_r$

A Art. 1.3.2

$$\Sigma \eta_i \gamma_i Q_i \leq \phi R_n.$$

A Eq. 1.3.2.1-1

For loads for which a maximum value of γ_i is appropriate,

$$\eta_i = \eta_D \eta_R \eta_I \geq 0.95$$

A Eq. 1.3.2.1-2

For loads for which a minimum value of γ_i is appropriate,

$$\eta_i = \frac{1}{\eta_D \eta_R \eta_I} \leq 1.0$$

A Eq. 1.3.2.1-3

Load Combinations and Load Factors

Please see Tables 1.1 (**A Tbl. 3.4.1-1**) and 1.2 (**A Tbl. 3.4.1-2**), which show the load factors for various load combinations and permanent loads.

Loads and Load Designation

A Art. 3.3.2

The following permanent and transient loads and forces shall be considered in bridge design:

Permanent Loads

CR = force effects due to creep
DD = downdrag force
DC = dead load of structural components and nonstructural attachments
DW = dead load of wearing surfaces and utilities
EH = horizontal earth pressure load

TABLE 1.1 (AASHTO Table 3.4.1-1)

Load Combinations and Load Factors

Load Combination Limit State	*DC* *DD* *DW* *EH* *EV* *ES* *EL* *PS* *CR* *SH*	*LL* *IM* *CE* *BR* *PL* *LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time *EQ*	*IC*	*CT*	*CV*
Strength I (unless noted)	γp	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Strength II	γp	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Strength III	γp	—	1.00	1.40	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Strength IV	γp	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—
Strength V	γp	1.35	1.00	0.40	1.0	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Extreme Event I	γp	γEQ	1.00	—	—	1.00	—	—	—	1.00	—	—	—
Extreme Event II	γp	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00
Service I	1.00	1.00	1.00	0 30	1.0	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—
Service III	1.00	0.80	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—
Service IV	1.00	—	1.00	0.70	—	1.00	1.00/1.20	—	1.0	—	—	—	—
Fatigue I— *LL, IM, & CE* only	—	1.50	—	—	—	—	—	—	—	—	—	—	—
Fatigue II— *LL, IM, & CE* only	—	0.75	—	—	—	—	—	—	—	—	—	—	—

TABLE 1.2 (**AASHTO Table 3.4.1-2**)

Load Factors for Permanent Loads, γ_p

Type of Load. Foundation Type, and Method Used to Calculate Downdrag		Load Factor	
		Maximum	**Minimum**
DC: Component and Attachments		1.25	0.90
DC: Strength IV only		1.50	0.90
DD: Downdrag	Piles, α Tomlinson Method	1.4	0.25
	Piles. λ Method	1.05	0.30
	Drilled shafts. O'Neill and Reese (1999) Method	1.25	0.35
DW: Wearing Surfaces and Utilities		1.50	0.65
EH: Horizontal Earth Pressure			
• Active		1.50	0.90
• At-Rest		1.35	0.90
• *AEP* for Anchored Walls		1.35	N/A
EL: Locked-in Construction Stresses		1.00	1.00
EV: Vertical Earth Pressure			
• Overall Stability		1.00	N/A
• Retaining Walls and Abutments		1.35	1.00
• Rigid Buried Structure		1.30	0.90
• Rigid Frames		1.35	0.90
ES: Earth Surcharge		1.50	0.75

EL = miscellaneous locked-in force effects resulting from the construction process, including jacking apart of cantilevers in segmental construction

ES = earth surcharge load

EV = vertical pressure from dead load of earth fill

PS = secondary forces from posttensioning

SH = force effects due to shrinkage

γp = load factor for permanent loading

Transient Loads

BR = vehicular braking force

CE = vehicular centrifugal force

CT = vehicular collision force

CV = vessel collision force

EQ = earthquake load

FR = friction load

IC = ice load
IM = vehicular dynamic load allowance
LL = vehicular live load
LN = design lane load
LS = live load surcharge
PL = pedestrian live load
SE = force effect due to settlement
TG = force effect due to temperature gradient
TL = design truck load or design tandem load
TU = force effect due to uniform temperature
WA = water load and stream pressure
WL = wind on live load
WS = wind load on structure

Strength Limit States for Superstructure Design

The load effect, Q, is given in the following equations in relation to various limit states:

Strength I: Q = 1.25 DC + 1.5 DW + 1.75 LL; LL = TL + LN
Strength II: Q = 1.25 DC + 1.5 DW + 1.35 LL
Strength III: Q = 1.25 DC + 1.5 DW + 1.4 WS
Strength IV: Q = 1.5 DC + 1.5 DW
Service I: Q = 1.0 DC + 1.0 DW + 1.0 LL + 1.0 WA + 0.3 WS + 1.0 WL
Service II: Q = 1.0 DC + 1.0 DW + 1.3 LL
Service III: Q = 1.0 DC + 1.0 DW + 0.8 LL +1.0 WA
Fatigue I: Q = 1.5 (LL + IM)
Fatigue II: Q = 0.75 (LL + IM)

Resistance Factors, Φ, for Strength Limits

Resistance factors, Φ, for strength limit states are given for various structural categories in AASHTO. Selected resistance factors that are most frequently encountered follow.

For service and extreme event limit states, resistance factors ϕ shall be taken as 1.0, except for bolts.

A Art. 1.3.2.1

Flexure and tension in reinforced concrete : 0.90

A Art. 5.5.4.2

Flexure and tension in prestressed concrete	:	1.00
Shear in concrete	:	0.90
Axial compression in concrete	:	0.75
Flexure in structural steel	:	1.00

A Art. 6.5.4.2

Shear in structural steel	:	1.00
Axial compression in structural steel	:	0.90
Tension, yielding in gross section	:	0.95

Design Live Load HL-93

HL-93 is a notional live load where H represents the HS truck, L the lane load, and 93 the year in which the design live load HL-93 was adopted.

The design live load designated as the HL-93 consists of a combination of:

A Art. 3.6.1.2

- Design truck (HS-20) or design tandem (a pair of 25 kip axles 4 ft apart),
- Design lane load of 0.64 kip-ft uniformly distributed in the longitudinal direction. Transversely the design lane load is distributed over a 10 ft width within a 12 ft design lane. Note that the design lane load is not subject to dynamic allowance.

For both design truck and design tandem loads, the transverse spacing of wheels is taken as 6.0 ft. The uniform lane load may be continuous or discontinuous as necessary to produce the maximum force effect.

Fatigue Live Load

The fatigue load will be one truck or axles as specified in Figure 1.1 (A Art. 3.6.1.2.2) with a constant spacing of 30 ft between the 32.0 kip axles. The frequency of the fatigue load shall be taken as the single-lane average daily truck traffic. When the bridge is analyzed by approximate load distribution (A Art. 4.6.3), the distribution factor for one traffic lane shall be used. See Figure 1.2.

A Art. 3.6.1.4

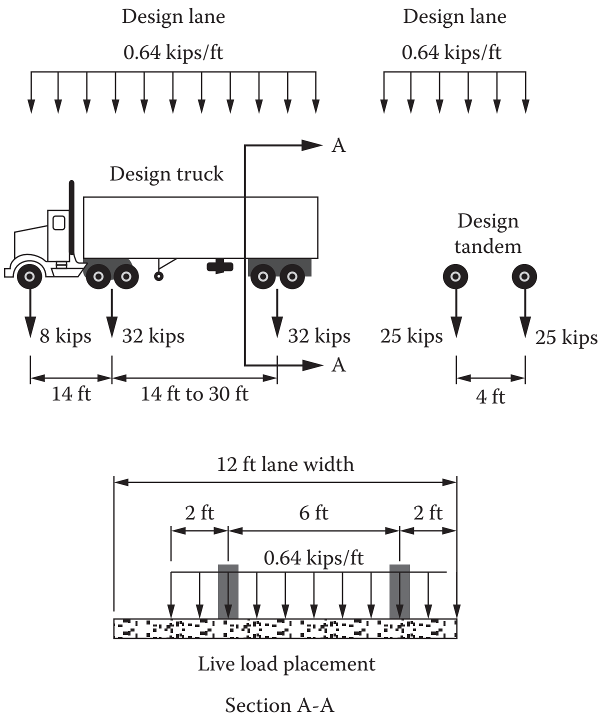

FIGURE 1.1
Design truck (HS-20), design tandem load (a pair of 25 kip axles 4 ft apart), and design lane load (0.64 kips/ft longitudinally distributed). (*Source:* **Art. 3.6.1.2.2.**)

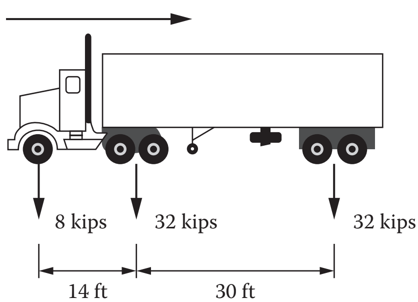

FIGURE 1.2
Fatigue live loading. (*Source:* **Art. 3.6.1.4.**)

Number of Design Lanes, N_L

The number of design lanes, N_L, is the integer portion of the ratio of the clear roadway width (ft), w, and the width of the design traffic lane (12 ft). For example, if the clear roadway width is 40 ft,

A Art. 3.6.1.1.1

$$N_L = \frac{w}{12.0\,\frac{\text{ft}}{\text{lane}}} = \frac{40\,\text{ft}}{12.0\,\frac{\text{ft}}{\text{lane}}} = 3.33 \text{ lanes (3 lanes)}$$

Multiple Presence Factor of Live Load, m

Design trucks will be present in adjacent lanes on roadways with multiple design lanes. Because it is unlikely that three or more adjacent lanes will be loaded simultaneously with trucks, adjustments in design loads are necessary. These factors have been implicitly included in the approximate equations for distribution factors and should be removed for fatigue investigations. See Table 1.3.

A Art 3.6.1.1.2

Therefore for fatigue investigations in which the traffic truck is placed in a single lane, the factor of 1.2 which has been included in the approximate equations should be removed.

A Com. 3.6.1.1.2

The multiple presence m is defined for sites with an ADTT of 5,000 trucks or greater in one direction. For sites with a lower ADTT, reduce force effects by:

TABLE 1.3 (AASHTO Table 3.6.1.1.2-1)

Multiple Presence Factors, m

A Art. 3.6.1.1.2

Number of Loaded Lanes	Multiple Presence Factors, m
1	1.20
2	1.00
3	0.85
>3	0.65

$$100 < \text{ADTT} < 1{,}000 \rightarrow 95\%$$

$$\text{ADTT} < 100 \rightarrow 90\%$$

This adjustment is based on the reduced probability of attaining the design event during a 75-year design life with reduced truck volume.

Dynamic Load Allowance, IM

The dynamic load allowance, IM, is applied only to the design truck load, or tandem, not to the design lane load. The static effects of the design truck or tandem shall be increased for dynamic load allowance. Table 1.4 indicates the dynamic load allowance for different components under different limit states.

A Art. 3.6.2

Live Load Distribution Factors

Live load distribution factors in AASHTO are lane-load distributions, not wheel-load distributions as they were in the *AASHTO Standard Specifications for Highway Bridges*, 17th edition, 2002.

A Art. 4.6.2.2: Appendices A–D

The distribution factors are included in several AASHTO articles, and important provisions are in AASHTO Sec. 4.

The live load moment and shear for beams or girders are determined by applying the lane fraction (distribution factor) in AASHTO Art. 4.6.2.2.2 to the moment and shear due to the loads assumed to occupy 10 ft. transversely within a design lane.

AASHTO 3.6.1.2.1

TABLE 1.4 (AASHTO Table 3.6.2.1-1)
Dynamic Load Allowance, IM

Component	IM (%)
Deck joints, all limit states	75
All other components	
Fatigue and fracture limit state	15
All other limit states	33

Distribution factors are most sensitive to beam (girder) spacing. Span length and longitudinal stiffness have smaller influences.

Load-carrying capacity of exterior beams (girders) shall not be less than that of interior beams (girders).

A Art. 2.5.2.7.1

Because of the many algebraically complex expressions and equations associated with live load distribution, they are discussed in detail in example problems.

Load Combinations for the Strength I Limit State

The total factored force effects, Q, shall be taken as

A Arts 3.3.2, 3.4.1, Tbls. 3.4.1-1, 3.4.1-2

$$Q = \Sigma \eta_i \gamma_i Q_i$$

Where:

η_i = load modifier = 1.0
γ_i = load factor

A Eq. 3.4.1-1

For load combination limit state Strength I,

Q = 1.25 DC + 1.50 DW + 1.75 (TL + LN)
M_u = 1.25 MDC +1.50 MDW + 1.75 (MTL + MLN)
$V_u = 1.25\ V_{DC} + 1.50\ V_{DW} + 1.75\ (V_{TL} + V_{LN})$
TL = Truck load or tandem load
LN = Lane load
η_D = 1.0 for conventional designs

A Art. 1.3

η_R = 1.0 for conventional levels of redundancy
η_I = 1.0 for typical bridges
Φ = 1.0 for service and fatigue limit states

A 13.2.1; A 5.5.4.2; A 6.5.4.2; A C6.6.1.2.2

ϕ For concrete structures and steel structures, refer to Art. 5.5.4.2.1 and Art. 6.5.4.2, respectively.

Unfactored Dead Load Moments and Shears

M_{DC} = Maximum unfactored moment due to DC
M_{DW} = Maximum unfactored moment due to DW
V_{DC} = Maximum unfactored shear due to DC
V_{DW} = Maximum unfactored shear due to DW

Unfactored Live Load Moments per beam with Distribution Factors DFM, and Dynamic Allowance IM

M_{TL} = (maximum truck or tandem load moment per lane due to design truck load) (DFM) (1 + IM)
M_{LN} = (maximum lane load moment per lane) (DFM)*

Unfactored Live Load Shear per Beam with Distribution Factors DFV, and Dynamic Allowance, IM

V_{TL} = (maximum truck load per shear lane) (DFV) (1+IM)
V_{LN} = (maximum lane load shear per lane) (DFV)[2]

Live Load Distribution Factors for Moment for Beams

DFM_{si} = Single (one) lane loaded for moment in interior beams
DFM_{mi} = Multiple (two or more) lanes loaded for moment in interior beams
DFM_{se} = Single (one) lane loaded for moment in exterior beams
DFM_{me} = Multiple (two or more) lanes loaded for moment in exterior beams

Live Load Distribution Factors for Shear for Beams

DFV_{si} = Single (one) lane loaded for shear in interior beams
DFV_{mi} = Multiple (two or more) lanes loaded for shear in interior beams
DFV_{se} = Single (one) lane loaded for shear in exterior beams
DFV_{me} = Multiple (two or more) lanes loaded for shear in exterior beams

* No impact allowance applies.

Simple Beam Live Load Moments and Shears Carrying Moving Concentrated Loads per Lane

The maximum moment occurs under one of the loads when that load is as far from one support as the center of gravity of all the moving loads on the beam is from the other support. This condition occurs when the center of the span is midway between the center of gravity of the moving loads and the nearest concentrated load where the maximum moment occurs.

The maximum shear due to moving loads occurs at one support when one of the moving loads is at that support. With several moving loads, the location that will produce maximum shear must be determined by trial and error, as shown. Because the maximum moments for uniform loads such as the lane loads and dead loads occur at midspan, the maximum design truck or tandem moment is generally used with the HL-93 center axle at midspan. See Figures 1.3 and 1.4.

Live Load Moments and Shears for Beams (Girders)

A Art. Tbls. 4.6.2.2.2b-1 and 4.6.2.2.2d-1; and 4.6.2.2.3a-1 and 4.6.2.2.3b-1

Live load moments and shears for beams (girders) are determined by applying the distribution factors for live loads per lane in AASHTO tables in 4.4.2.2 to the moment and shears due to the live loads assumed to occupy 10 ft. within a design lane (AASHTO 3.6.1.2.1).

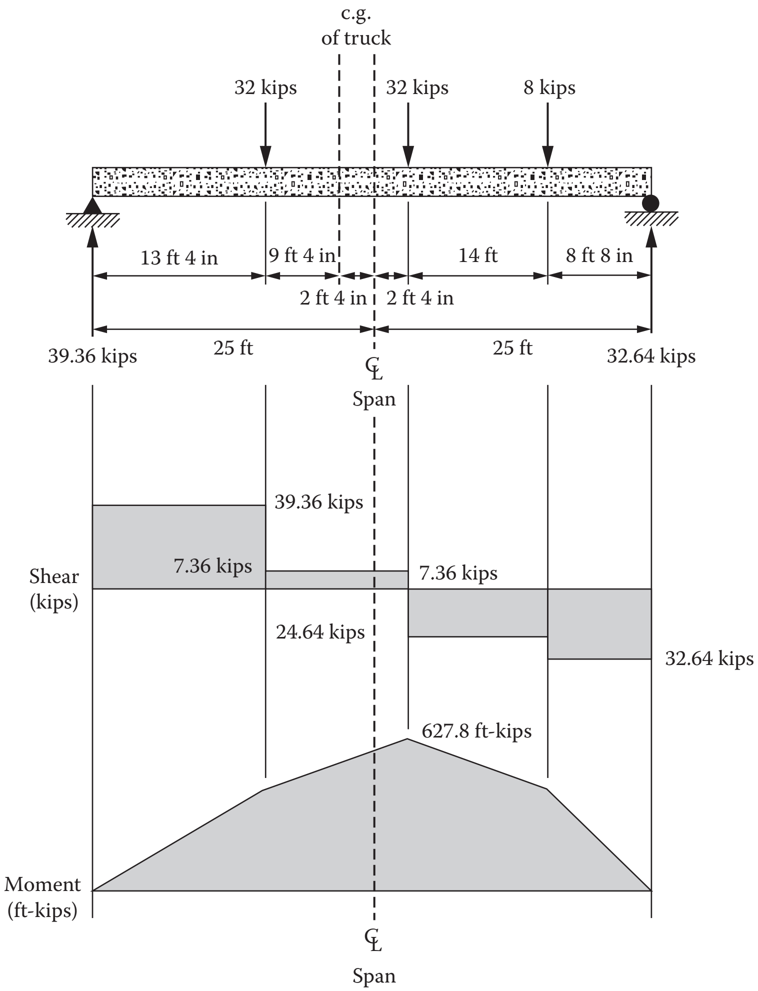

FIGURE 1.3
Shear and moment diagrams for controlling design truck (HS-20) live load position.

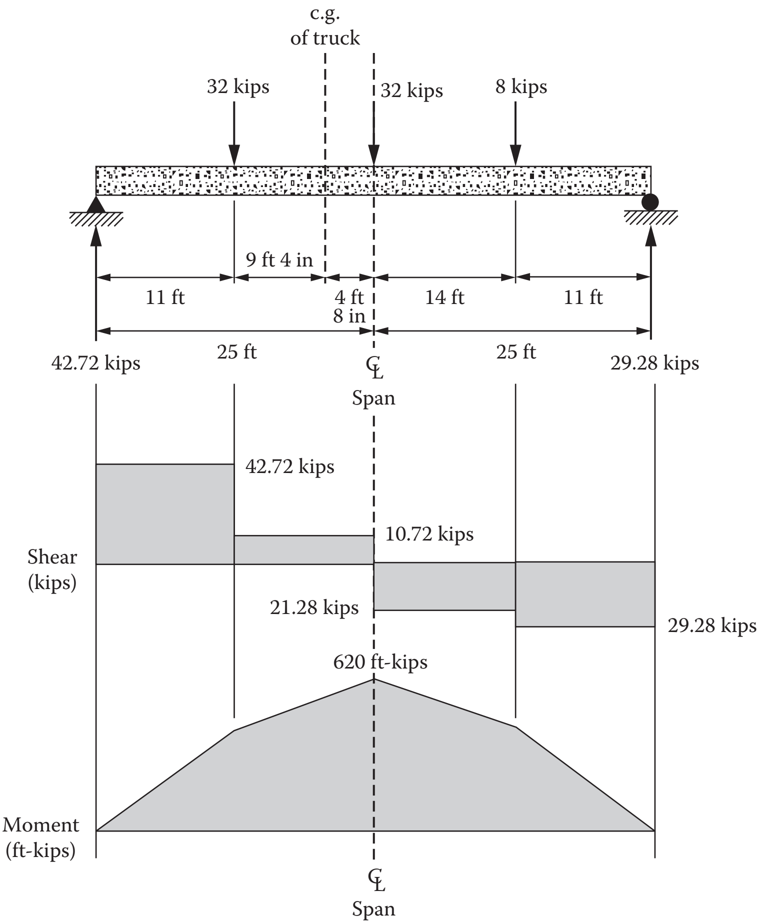

FIGURE 1.4
Shear and moment diagrams for the design truck (HS-20) center axle at midspan.