

LRFR Rating Factor Equation and Load Factors

Load and Resistance Factor Rating (LRFR) is the load rating method in Section 6, Part A of the AASHTO Manual for Bridge Evaluation (MBE). FHWA considers it the preferred method, and since October 1, 2010 FHWA policy has called for bridges designed by LRFD to be load rated by LRFR. This course takes apart the general load-rating equation term by term, shows where each load factor comes from in MBE Table 6A.4.2.2-1 and the legal and permit tables, explains the optional condition and system factors and their 0.85 floor, and works through numerical examples showing how inventory, operating, legal and permit results are read and used.

Learning objectives

- Write the LRFR rating factor equation
- Select design, legal and permit load factors
- Apply condition and system factors
- Interpret inventory and operating results

Why a rating factor and not a design check

A design check asks whether factored resistance is at least the sum of factored loads. A load rating asks a different question: *how many times can this bridge carry a specified vehicle* once its permanent loads have been paid for? The answer is the **rating factor (RF)**, the multiple of the rating vehicle's live load effect (moment, shear, axial force or stress) that the member can carry while still satisfying the limit state under investigation. An RF of 1.00 means the member carries the rating vehicle exactly at the limit; 1.40 means 40 percent of reserve; 0.80 means the member falls short by 20 percent.

Because the rating factor scales the vehicle, it also gives a tonnage directly. The weight of the rating vehicle in tons multiplied by the RF is the tonnage the bridge can safely carry for that vehicle. A Type 3 legal truck of 25 tons with an RF of 0.84 rates at 21 tons, a number that can go on a posting sign.

The MBE arranges LRFR as three sequential levels of evaluation, each with its own live load model and calibrated load factors:

1. **Design-load rating** (first level), using the HL-93 model of the AASHTO LRFD Bridge Design Specifications at Inventory and Operating levels.
2. **Legal-load rating** (second level), using AASHTO and state legal vehicles, the specialized hauling vehicles, and where required the FAST Act emergency vehicles. This level drives posting decisions.
3. **Permit-load rating** (third level), using the actual permit vehicle, applied only to bridges with sufficient capacity for legal loads.

The levels are designed to be run in order. A bridge that passes HL-93 at the Inventory level should have adequate capacity for AASHTO legal loads and state legal loads within the LRFD exclusion limits, so it usually does not need a legal-load rating. Automated programs often run all levels at once, but the logic of the sequence still governs how the results are used.

The general load-rating equation

MBE Article 6A.4.2.1 gives the general load-rating equation, applied to each component and connection for each force effect:

$$RF = [C - \gamma_{DC}(DC) - \gamma_{DW}(DW) \pm \gamma_P(P)] / [\gamma_{LL}(LL + IM)]$$

For the strength limit states, capacity is the factored nominal resistance:

$$C = \phi_c \phi_s \phi R_n, \text{ with the lower limit } \phi_c \phi_s \geq 0.85$$

For the service limit states, $C = f_R$, the allowable stress specified in the LRFD Specifications (for example, a stress limit in prestressed concrete or the Service II flange stress limit in steel).

The terms are:

- **RF**: rating factor.
- **C**: capacity.
- **R_n**: nominal member resistance, as inspected, so section loss and other deterioration are reflected.
- **DC**: dead load effect of structural components and attachments.
- **DW**: dead load effect of the wearing surface and utilities.
- **P**: permanent loads other than dead loads, such as secondary prestressing effects in continuous spans and locked-in effects from construction. Its load factor γ_P is 1.0.
- **LL**: live load effect of the rating vehicle; **IM**: dynamic load allowance.
- **γ_{DC} , γ_{DW}** : LRFD load factors for DC and DW; **γ_{LL}** : the evaluation live load factor.
- **ϕ_c** : condition factor; **ϕ_s** : system factor; **ϕ** : LRFD resistance factor.

The rating is carried out at each applicable limit state and load effect, and the lowest value determines the controlling rating factor. Members carrying combined effects (axial and bending, or shear and bending) are rated considering the interaction, as the MBE resistance articles provide.

The $\pm$ on the P term is a sign convention: P is added when it opposes the live load effect and subtracted when it adds to it. For most steel girders P is zero and the equation shortens to $RF = [C - \gamma_{DC}DC - \gamma_{DW}DW] / [\gamma_L(LL + IM)]$.

Load factors from MBE Table 6A.4.2.2-1

MBE Table 6A.4.2.2-1 assigns limit states and load factors by bridge type (steel, reinforced concrete, prestressed concrete, wood). The values below are from the Third Edition with 2018 and 2019 interim revisions.

Bridge type	Limit state	DC	DW	Design Inventory LL	Design Operating LL	Legal LL	Permit LL
Steel	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1, 3b-1	—
Steel	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
Steel	Service II	1.00	1.00	1.30	1.00	1.30	1.00

Steel	Fatigue	0.00	0.00	0.80	—	—	—
Reinforced concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1, 3b-1	—
Reinforced concrete	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
Reinforced concrete	Service I	1.00	1.00	—	—	—	1.00
Prestressed concrete	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1, 3b-1	—
Prestressed concrete	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1
Prestressed concrete	Service III	1.00	1.00	Table 6A.4.2.2-2	—	1.00	—
Prestressed concrete	Service I	1.00	1.00	—	—	—	1.00
Wood	Strength I	1.25	1.50	1.75	1.35	Tables 6A.4.4.2.3a-1, 3b-1	—
Wood	Strength II	1.25	1.50	—	—	—	Table 6A.4.5.4.2a-1

The table notes matter in practice:

- Gray-shaded cells in the MBE table mark optional checks (for example, steel fatigue at the inventory level and Service II for permits).
- Service I is used to check the $0.9F_y$ stress limit in reinforcing steel.
- **The DW load factor at the strength limit state may be taken as 1.25 where the wearing surface thickness has been field measured.** This is one of the cheapest rating improvements available: measure the overlay.
- The fatigue limit state is checked using the LRFD fatigue truck.

MBE Table 6A.4.2.2-2 sets the Service III live load factor for prestressed concrete at the design-load Inventory level: **1.0** for components rated using refined estimates of time-dependent losses per LRFD Article 5.9.5.4 together with the elastic gain, and **0.8** for all other prestressed concrete components.

Condition and system factors

The two factors that make LRFR capacity different from LRFD design resistance are ϕ_c and ϕ_s . Both apply only to strength limit states, and the MBE says their use may be considered optional based on the agency's load-rating practice.

Condition factor ϕ_c (Table 6A.4.2.3-1)

Structural condition of member	NBI condition rating (commentary)	ϕ_c
Good or Satisfactory	6 or higher	1.00
Fair	5	0.95

Poor	4 or lower	0.85
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The commentary explains why: once a member begins to deteriorate, the scatter in its resistance grows, and deteriorated members tend to deteriorate faster. Part of ϕ_c covers possible further section loss before the next inspection. Better inspection and field measurement reduce, but do not eliminate, that extra uncertainty. ϕ_c is applied on top of a resistance already computed from the as-inspected section, so it is not a substitute for measuring section loss.

System factor ϕ_s (Table 6A.4.2.4-1)

Superstructure type	ϕ_s
Welded members in two-girder/truss/arch bridges	0.85
Riveted members in two-girder/truss/arch bridges	0.90
Multiple eyebar members in truss bridges	0.90
Three-girder bridges with girder spacing ≤ 6 ft	0.85
Four-girder bridges with girder spacing ≤ 4 ft	0.95
All other girder bridges and slab bridges	1.00
Floorbeams with spacing > 12 ft and noncontinuous stringers	0.85
Redundant stringer subsystem between floorbeams	1.00

System factors reflect redundancy of the whole superstructure: less redundant systems require their members to carry a higher safety margin. A system factor of 1.0 is used when checking shear at the strength limit state. When nonredundant superstructures are rated for legal loads with the generalized load factors, the system factors give a more consistent evaluation of system safety. For riveted and bolted gusset plates and their connections, the system factor for both strength and service force effects should be taken as 0.90.

The 0.85 floor

The product $\phi_c\phi_s$ may not be taken below 0.85. A welded two-girder bridge ($\phi_s = 0.85$) in poor condition ($\phi_c = 0.85$) gives a raw product of 0.7225, but the capacity uses 0.85. The floor prevents the two penalties from compounding beyond what the calibration supports.

Part A — The denominator: live load and dynamic load allowance

Everything in the numerator of the rating equation is about what the member has left after permanent loads. Everything in the denominator describes the vehicle being rated. Getting the denominator right is as important as getting the capacity right, because a 10 percent error in LL + IM is a 10 percent error in the rating factor.

Design-load rating: HL-93

The first level of evaluation applies the HL-93 notional live load model of the LRFD Specifications, including the dynamic load allowance, so that the rating is consistent with the loading used to design the bridge. HL-93 combines a design truck (8-kip front axle and two 32-kip axles, with the front spacing at 14 ft and the rear spacing variable from 14 to 30 ft) or a design tandem (a pair of 25-kip axles spaced 4 ft apart) with a design lane load of 0.64 kip per linear foot. For negative moment

between points of contraflexure and for interior pier reactions, the LRFD Specifications add a case of 90 percent of two design trucks spaced at least 50 ft apart plus 90 percent of the lane load.

HL-93 was developed as a notional representation of the shear and moment produced by groups of vehicles routinely permitted on highways under "grandfather" exclusions to weight laws. It is not a real truck, which is why HL-93 results are expressed as a rating factor rather than a tonnage.

Dynamic load allowance

LRFD Article 3.6.2.1 sets IM as a percentage increase applied to the static effects of the design truck or tandem: 75 percent for deck joints at all limit states, 15 percent for the fatigue and fracture limit state, and 33 percent for all other components and limit states. IM is not applied to the design lane load. A common software or hand-calculation error is to multiply the combined truck-plus-lane effect by 1.33; the correct form is $1.33 \times \text{truck} + \text{lane}$.

For legal-load rating the MBE uses the LRFD dynamic load allowance, except that for longitudinal members with spans greater than 40 ft the dynamic load allowance may be decreased based on the observed riding surface condition, as provided in the commentary to MBE Article 6A.4.4.3. That reduction depends on the inspection record of the approach and deck riding surface, MBE Table C6A.4.4.3-1 ties the reduced value to the riding surface; the MBE Appendix A steel example, for instance, uses 20 percent instead of 33 percent after a field evaluation verified that the approach and bridge riding surfaces had only minor surface deviations or depressions. That is one more reason the rating engineer needs a recent, thorough inspection rather than a general condition description.

Distribution factors and multiple presence

For design-load and legal-load ratings the live load effect per girder normally comes from the LRFD distribution factors, which already include the multiple presence factors (1.20 for one loaded lane). That is appropriate for HL-93 and for routine traffic. It is not appropriate when the live load factor was calibrated for a single heavy vehicle: for special permits, the MBE directs that the 1.20 single-lane multiple presence factor built into the LRFD one-lane distribution factor be divided out, because it relates specifically to the HL-93 model. The FHWA emergency-vehicle guidance similarly allows the 1.2 factor to be divided out for a one-lane bridge.

Part B — Inventory and Operating in the design-load rating

The design-load rating keeps the traditional two rating levels:

- **Inventory** uses $\gamma_{LL} = 1.75$ at Strength I, the same live load factor as LRFD design. An Inventory RF of 1.0 or more means the bridge meets the reliability level of a new LRFD design for HL-93.
- **Operating** uses $\gamma_{LL} = 1.35$ at Strength I, a lower target reliability that reflects the shorter exposure period assumed for rating and the fact that the load will be checked again at the next inspection.

Since only the live load factor changes between the two levels, the Operating RF at Strength I is always the Inventory RF multiplied by $1.75/1.35 = 1.296$ for the same member and effect. If a program reports otherwise, something other than the live load factor changed.

The design-load rating also works as a screen:

- A bridge that passes HL-93 at the **Inventory** level should have adequate capacity for AASHTO legal loads and state legal loads within the exclusion limits described in the LRFD Specifications.
- A bridge that passes HL-93 only at the **Operating** level should have adequate capacity for AASHTO legal loads, but may not rate ($RF < 1.0$) for state legal loads, especially vehicles significantly heavier than the AASHTO trucks.
- A bridge with an Operating RF below 1.0 needs a legal-load rating to decide whether posting or strengthening is needed.

For steel, the Strength I and Service II load combinations should be checked for the design loading. The Service II live load factor is 1.30 at Inventory and 1.00 at Operating, and the Service II check limits permanent deformation from flange yielding under overloads. The fatigue limit state with $\gamma_{LL} = 0.80$ and the LRFD fatigue truck is an optional Inventory-level check for steel. For prestressed concrete, Service III at the Inventory level uses the factor from Table 6A.4.2.2-2 (1.0 or 0.8 as described earlier), and the design-load Operating level has no Service III check.

Which results get reported

Under the SNBI, load rating results are reported in items B.LR.01 through B.LR.08: Design Load, Design Method, Load Rating Date, Load Rating Method, Inventory Load Rating Factor, Operating Load Rating Factor, Controlling Legal Load Rating Factor and Routine Permit Loads. The point here is that the reported Inventory and Operating factors come from this equation and must be the controlling (minimum) values across all members, limit states and force effects, not the values for the member someone happened to check first.

Part C — Legal-load factors and their calibration

The second level of evaluation, legal-load rating, establishes whether posting or strengthening is needed. Posting or strengthening is needed when the controlling legal-load rating factor is less than 1.0. That threshold corresponds to a minimum target reliability index β_T of 2.5. Bridges with legal-load rating factors greater than 1.0 may then be evaluated for overweight permits.

The Strength I live load factors for legal loads depend on the average daily truck traffic in one direction. Since the 2013 interim revisions, following NCHRP Project 12-78, the factors are the same for routine commercial traffic (Table 6A.4.4.2.3a-1) and for specialized hauling vehicles (Table 6A.4.4.2.3b-1):

Traffic volume (one direction)	γ_L
Unknown	1.45
$ADTT \geq 5,000$	1.45
$ADTT \leq 1,000$	1.30

Linear interpolation is permitted between 1,000 and 5,000. FHWA requires ADTT to be recorded for all bridges; where site traffic conditions are unknown, worst-case traffic should be assumed. The Service II live load factor for legal-load rating of steel is 1.30, and the Strength I and Service II combinations are both mandatory for steel legal-load ratings.

The engineer is allowed to go the other way too. If in the engineer's judgment an increase is warranted for conditions not covered by the Manual, the factors in Table 6A.4.4.2.3a-1 may be increased, but not beyond the tabulated value multiplied by 1.3. The MBE also allows site-specific live load factors from weigh-in-motion data, provided comparable target reliability is achieved.

The generalized factors are intended for AASHTO legal loads and for state legal loads with only minor variations from them. State legal loads with gross weights significantly greater than the AASHTO legal loads should preferably be rated using the routine permit load factors instead.

Legal load models in brief

The routine commercial family is the AASHTO Type 3, Type 3S2 and Type 3-3 trucks, which model the short, medium and long span portions of the federal bridge formula. For spans up to 200 ft only the vehicle is placed in the lane. For spans over 200 ft the Type 3-3 multiplied by 0.75 is combined with a 0.2 kip per foot lane load, and for negative moments and interior reactions, regardless of span, two Type 3-3 trucks multiplied by 0.75 and spaced 30 ft apart are combined with the 0.2 kip per foot lane load. The specialized hauling vehicles (SU4, SU5, SU6, SU7) and the Notional Rating Load, and the FAST Act emergency vehicles EV2 and EV3, are covered in course BR-L02. For emergency vehicles, FHWA's guidance allows a live load factor of 1.3 and placement of the emergency vehicle in only a single lane of one direction.

Part D — Permit-load factors

The third level of evaluation reviews the safety and serviceability of a bridge for a vehicle heavier than the legal limits. It should only be applied to bridges that have sufficient capacity for legal loads. The live load is the actual permit vehicle, with its gross weight and axle configuration. Permits are checked at the **Strength II** limit state, and for steel the **Service II** check ($\gamma_{LL} = 1.00$) is optional to limit permanent deformation. For reinforced and prestressed concrete, Table 6A.4.2.2-1 lists Service I with a live load factor of 1.00 for permits, which is how the $0.9F_y$ limit on reinforcing steel stress is checked.

The MBE recognizes two permit classes. **Routine (annual) permits** are usually valid for unlimited trips over a period up to one year. **Special (limited-crossing) permits** are usually valid for a single trip or a limited number of trips for a vehicle of specified configuration, axle weights and gross weight, and those vehicles are usually heavier.

For spans up to 200 ft only the permit vehicle is considered present in the lane. For spans between 200 and 300 ft, and when checking negative moments in continuous spans, a 0.2 kip per foot lane load is added in each lane to simulate closely following vehicles, applied only where it adds to the permit effects.

Routine permits (Table 6A.4.5.4.2a-1)

Routine permit ratings use the LRFD multi-lane distribution factors, which assume two equally heavy vehicles side by side. The live load factors decrease as the permit gets heavier, reflecting the small likelihood of the simultaneous events that the multi-lane distribution factor already assumes. They depend on ADTT and on the **Permit Weight Ratio (PWR)**, the gross vehicle weight divided by the front-axle-to-rear-axle length, counting only the axles on the superstructure. As summarized for steel bridges by NSBA's Steel Bridge Design Handbook, the factors are:

Distribution factor	ADTT (one direction)	PWR $\leq$ 2.0 kip/ft	2.0 to 3.0 kip/ft	PWR $\geq$ 3.0 kip/ft
Two or more lanes	> 5,000	1.40	1.35	1.30
Two or more lanes	1,000	1.35	1.25	1.20
Two or more lanes	< 100	1.30	1.20	1.15
One lane	All ADTTs	1.40		

Linear interpolation is permitted for ADTT and weight between the tabulated limits. Check the exact boundary wording and any later interim revisions in your edition of the MBE before relying on a value at a boundary.

Special permits

Special permit factors are for use with the one-lane LRFD distribution factor, with the 1.20 single-lane multiple presence factor divided out. The live load factor accounts for the probable weight of an adjacent random truck when the bridge is open to other traffic:

Trip type	Traffic condition	DF	Y _L
Single trip	Escorted, no other vehicles on the bridge	One lane	1.10
Single trip	Mixed with traffic	One lane	1.20
Multiple trips (fewer than 100 crossings)	Mixed with traffic	One lane	1.40

Permits with refined analysis

When a multi-girder bridge is analyzed by a refined method instead of LRFD distribution factors, the MBE adjusts the permit factors: for routine permits, add 0.10 to the tabulated factor and place two permit trucks in adjacent lanes; for escorted special permits with no other vehicles, apply 1.1 to the permit vehicle; for special permits mixed with traffic, apply 1.0 to the permit truck and 1.10 to the governing AASHTO legal truck in the adjacent lane. If an escorted special permit crosses at crawl speed (under 10 mph) and dynamic load allowance is neglected, the Table 6A.4.5.4.2a-1 factor is increased by 1.05 to keep the reliability index at or above the minimum of 1.50.

Part E — Choosing limit states for each level

Strength is the primary limit state for load rating. Service and fatigue limit states are applied selectively, as the MBE resistance articles direct. A practical checklist for each level and material, drawn from Table 6A.4.2.2-1, is:

Level	Steel	Reinforced concrete	Prestressed concrete	Wood
Design Inventory	Strength I (1.75); Service II (1.30); Fatigue (0.80, optional)	Strength I (1.75)	Strength I (1.75); Service III (Table 6A.4.2.2-2)	Strength I (1.75)
Design Operating	Strength I (1.35); Service II (1.00)	Strength I (1.35)	Strength I (1.35)	Strength I (1.35)
Legal	Strength I (Tables 6A.4.4.2.3a-1, 3b-1); Service II (1.30)	Strength I	Strength I; Service III (1.00)	Strength I
Permit	Strength II; Service II (1.00, optional)	Strength II; Service I (1.00)	Strength II; Service I (1.00)	Strength II

Some of these checks are shaded as optional in the MBE table, and owner policy may make them mandatory or waive them, so a rating report should state which checks were run and why. A rating that only checks Strength I for a prestressed girder may overstate the rating if the owner requires Service III at the legal level.

Service checks have no condition or system factor

Because ϕ_c and ϕ_s apply only to strength limit states, a service check uses the full stress limit f_R with no reduction for condition or redundancy. Deterioration still enters through the section properties used to compute stresses (for example, a reduced section modulus for a corroded flange), so the service rating does respond to condition; it just does so through the analysis rather than a factor.

Interaction and connections

Every primary component and its connections should be rated to find the governing element. The I-35W collapse in Minneapolis in August 2007, which NTSB attributed to inadequate load capacity of gusset plates caused by a design error, reinforced that connections must be rated as well as members. FHWA issued gusset plate rating guidance (FHWA-IF-09-014) in 2009, and the MBE now includes gusset plate provisions, covered in course BR-L05.

Part F — Worked example 1: design-load rating of a steel girder

The numbers in these examples are illustrative, chosen to show the arithmetic. They are not from a real bridge.

Given: an interior girder of a simple-span composite steel multi-girder bridge with six girders at 8 ft spacing, in Satisfactory condition. At midspan:

- Factored flexural resistance $\phi R_n = \phi_f M_n = 1.00 \times 6,000 = 6,000$ kip-ft ($\phi_f = 1.00$ for steel flexure in LRFD).
- DC = 1,100 kip-ft (girder, slab, haunch, diaphragms, barriers distributed).
- DW = 200 kip-ft (bituminous overlay, thickness taken from plans).
- HL-93 LL + IM per girder (distribution factor applied, 33 percent IM on truck only) = 1,500 kip-ft.

Factors: $\phi_c = 1.00$ (Satisfactory); $\phi_s = 1.00$ (girder bridge, not in a reduced category). $\phi_c \phi_s = 1.00 \geq 0.85$, so $C = 6,000$ kip-ft.

Numerator = $6,000 - 1.25(1,100) - 1.50(200) = 6,000 - 1,375 - 300 = 4,325$ kip-ft.

Inventory: $RF = 4,325 / (1.75 \times 1,500) = 4,325 / 2,625 = \mathbf{1.65}$.

Operating: $RF = 4,325 / (1.35 \times 1,500) = 4,325 / 2,025 = \mathbf{2.14}$. Check: $1.65 \times 1.296 = 2.14$.

Effect of measuring the overlay. If the inspector cores or probes the overlay and records its thickness, γ_{DW} may be taken as 1.25. The numerator becomes $6,000 - 1,375 - 250 = 4,375$ and the Inventory RF becomes $4,375 / 2,625 = 1.67$. The gain is small here because DW is small, but on a bridge with several inches of overlay and a marginal rating the change can decide whether the bridge passes.

Service II. Suppose the composite section has, at the bottom flange, a DC stress of 18.0 ksi, a DW stress of 3.0 ksi and an HL-93 LL + IM stress of 12.0 ksi, with $F_{yf} = 50$ ksi. The LRFD Service II flange limit for composite sections is $0.95R_h F_{yf}$; with $R_h = 1.0$ (homogeneous girder), $f_R = 47.5$ ksi. Inventory Service II $RF = (47.5 - 18.0 - 3.0) / (1.30 \times 12.0) = 26.5 / 15.6 = 1.70$; Operating = $26.5 / 12.0 = 2.21$. Neither ϕ_c nor ϕ_s applies. Strength I controls at Inventory ($1.65 < 1.70$).

Part G — Worked example 2: the same girder after deterioration

Ten years later the bottom flange near midspan has measurable corrosion loss. The inspection documents remaining flange thickness, and the rating engineer recomputes $M_n = 5,400$ kip-ft from the measured section. The superstructure is now rated Poor (4).

Factors: $\phi_c = 0.85$ (Poor); $\phi_s = 1.00$. Product = 0.85, exactly at the floor. $C = 0.85 \times 1.00 \times 5,400 = 4,590$ kip-ft.

Numerator = $4,590 - 1,375 - 300 = 2,915$ kip-ft.

Inventory RF = $2,915 / 2,625 = 1.11$. **Operating RF** = $2,915 / 2,025 = 1.44$.

The Inventory rating dropped from 1.65 to 1.11, a 33 percent reduction, although nominal resistance dropped only 10 percent. That leverage is normal: every kip-ft lost from capacity comes entirely out of the live-load reserve, because the dead load does not change. This is why accurate section loss measurement matters more than any single factor in the equation.

The condition factor was applied to a resistance already reduced for measured section loss. That is what the MBE intends: R_n reflects what has been lost, and ϕ_c covers the larger uncertainty and the likely further loss before the next inspection. Some owners view applying ϕ_c on top of carefully measured section loss as double counting and address it in their rating policy; course BR-L04 discusses how to document that choice.

Part H — Worked example 3: the 0.85 floor on a nonredundant bridge

Given: a welded two-girder bridge, superstructure in Poor condition. $\phi_s = 0.85$ (welded members in a two-girder bridge) and $\phi_c = 0.85$ (Poor). The raw product is $0.85 \times 0.85 = 0.7225$.

Because $\phi_c\phi_s$ may not be less than 0.85, use 0.85. If $\phi R_n = 9,000$ kip-ft, $C = 0.85 \times 9,000 = 7,650$ kip-ft, not $0.7225 \times 9,000 = 6,503$ kip-ft. With DC = 3,200, DW = 400 and HL-93 LL + IM = 2,000 kip-ft per girder:

- Numerator = $7,650 - 4,000 - 600 = 3,050$ kip-ft.
- Inventory RF = $3,050 / 3,500 = 0.87$; Operating RF = $3,050 / 2,700 = 1.13$.

Applying the raw product would have given a numerator of 1,903 and an Operating RF of 0.70, an error that would trigger an unnecessary legal-load evaluation and possibly an unnecessary posting.

For the girder shear check on the same bridge, $\phi_s = 1.0$, so only $\phi_c = 0.85$ applies. For the riveted gusset plates of a truss, the system factor would be 0.90 for both strength and service effects.

Part I — Worked example 4: legal-load rating and posting arithmetic

Given: an older steel stringer in Fair condition ($\phi_c = 0.95$) on a multi-stringer bridge ($\phi_s = 1.00$). The design-load Operating RF is below 1.0, so a legal-load rating is required. At midspan, ϕR_n (with measured section loss) = 1,263 kip-ft, so $C = 0.95 \times 1,263 = 1,200$ kip-ft. DC = 300 kip-ft and DW = 60 kip-ft. The AASHTO Type 3 legal truck (50 kips, 25 tons) produces LL + IM = 520 kip-ft per stringer.

Numerator = $1,200 - 1.25(300) - 1.50(60) = 1,200 - 375 - 90 = 735$ kip-ft.

Case 1 — ADTT unknown. $\gamma_L = 1.45$. $RF = 735 / (1.45 \times 520) = 735 / 754 = 0.97$. Safe load for the Type 3 = $0.97 \times 25 = 24.4$ tons. The RF is below 1.0, so posting or strengthening is needed for this vehicle.

Case 2 — ADTT counted at 3,000. Interpolating between 1.30 at 1,000 and 1.45 at 5,000: $\gamma_L = 1.30 + (3,000 - 1,000)/(5,000 - 1,000) \times 0.15 = 1.375$. $RF = 735 / (1.375 \times 520) = 735 / 715 = 1.03$. No posting needed for the Type 3.

Case 3 — ADTT 800. $\gamma_L = 1.30$. $RF = 735 / 676 = 1.09$.

The same member, unchanged, goes from "post" to "no posting" purely because a traffic count replaced the unknown-ADTT default. Recording an actual ADTT is a legitimate and inexpensive way to refine a marginal legal rating. Using an unsupported low ADTT to avoid a posting is not, and a reviewer should ask for the source of any ADTT used in a legal rating.

The legal-load rating must be repeated for each vehicle (Type 3S2, Type 3-3, the SHVs or the NRL, and the emergency vehicles where applicable) and the lowest result controls each posting decision. Course BR-L03 covers how agencies turn those rating factors into posting signs.

Part J — Worked example 5: a routine permit check

Given: the steel girder of Example 1 ($C = 6,000$ kip-ft, $DC = 1,100$, $DW = 200$), on a bridge with ADTT over 5,000. A routine permit applicant proposes a vehicle with a PWR under 2.0 kip/ft. Using the multi-lane distribution factor, the permit LL + IM = 2,100 kip-ft per girder.

γ_L (two or more lanes, $ADTT > 5,000$, $PWR \leq 2.0$) = 1.40, at Strength II. Dead load factors remain 1.25 and 1.50.

$RF = 4,325 / (1.40 \times 2,100) = 4,325 / 2,940 = 1.47 \geq 1.0$, so Strength II is satisfied.

For the optional Service II check with $\gamma_{LL} = 1.00$: if the permit LL + IM flange stress is 16.8 ksi, $RF = 26.5 / 16.8 = 1.58$, so permanent deformation is not a concern.

If the same vehicle were proposed as an escorted single-trip special permit with no other traffic, the engineer would use the one-lane distribution factor with the 1.20 multiple presence factor divided out and $\gamma_L = 1.10$. If the agency chose to analyze the girder system with a refined model for a routine permit, the factor would become $1.40 + 0.10 = 1.50$ with two permit trucks in adjacent lanes.

Part K — Reading and using rating results

A finished LRFR rating is a table of rating factors by member, location, force effect, limit state and vehicle. The controlling values are the minimums, and each level answers a different question:

- **Design Inventory $RF \geq 1.0$:** the bridge meets new-design reliability for HL-93. Legal-load ratings are generally not needed for routine traffic, although some owners still run state legal vehicles.
- **Design Operating $RF \geq 1.0$ but Inventory < 1.0 :** the bridge should carry AASHTO legal loads, but heavier state legal loads, SHVs and emergency vehicles need checking.
- **Design Operating $RF < 1.0$:** legal-load ratings are required to decide on posting.
- **Legal $RF < 1.0$ for any legal vehicle:** posting or strengthening is needed. $RF \times$ vehicle weight gives the tonnage for that vehicle type.
- **Legal $RF \geq 1.0$:** the bridge may be evaluated for permits.

- **Permit $RF \geq 1.0$:** the permit vehicle may cross under the conditions assumed (escort, traffic mix, number of trips, speed).

Bridge load ratings also feed agency decisions beyond posting: prioritizing repair, rehabilitation and replacement, distributing funds, and issuing overload permits. A rating that is too conservative costs money and access; one that is unconservative is a safety problem. Both are errors.

When to re-rate

Owners rate bridges at the completion of construction, when a change in condition suggests the rating may have changed, and when unusual loads are expected. Capacity tends to decrease with time from deterioration, live loads historically increase, and dead loads may increase through repairs and overlays. The MBE commentary (C6.1.1) says a load rating should not be undertaken without a recent thorough field inspection that provides the condition data needed for evaluation, minimizes the possibility of a gross error in assessing a component or connection, and improves safety through early discovery of deterioration. Under the NBIS, 23 CFR 650.313(k) requires each bridge to be rated for safe load capacity in accordance with Sections 6 and 8 of the AASHTO MBE, and requires new and updated load ratings to be completed as soon as practical but no later than 3 months after the initial inspection and when a change is identified that warrants re-rating, such as changes in condition, reconstruction, new construction, or changes in dead or live loads. Course BR-L03 covers the posting timelines in 650.313(l).

Part L — Common LRFR errors

1. **Applying $\phi_c \phi_s$ below 0.85.** The product has a floor; nonredundant bridges in poor condition are the usual victims.
2. **Applying ϕ_s to shear.** Use 1.0 for shear at the strength limit state.
3. **Applying ϕ_c or ϕ_s at service limit states.** They are strength-only factors.
4. **Using 1.75 for legal loads.** Legal loads use the ADTT-based factors (1.30 to 1.45 at Strength I), not the design Inventory factor.
5. **Using 1.50 for DW when the overlay has been measured,** or using 1.25 when it has not. The 1.25 value requires field measurement of the thickness.
6. **Applying IM to the lane load,** or applying a reduced IM without documenting the riding surface condition that justifies it.
7. **Leaving the 1.20 multiple presence factor in a special permit one-lane distribution factor.**
8. **Inconsistent dead loads.** Rating with plan DC while the inspection shows added overlays, utilities or barrier retrofits. DW and DC should reflect the bridge as it stands.
9. **Rating the girder but not the connections, floor system or substructure elements** that could govern. Gusset plates, pin-and-hanger assemblies, floorbeams and stringers frequently control older bridges.
10. **Reporting the Inventory and Operating factors from different members.** Each reported value should be the controlling minimum, and the report should identify which member and effect controlled.
11. **Using an unknown-ADTT factor of 1.30** or interpolating with an unsupported ADTT. Unknown traffic means worst case, 1.45.
12. **Mixing methods.** Combining LFR factors with LRFR equations, or LRFD resistance factors with LFR loads, produces numbers with no calibrated meaning.

Part M — Reviewer's checklist for an LRFR rating

Use this list when checking a consultant's or in-house LRFR rating package:

- Method stated as LRFR, with the MBE edition and interims identified, and consistent with owner policy (for LRFD-designed bridges, FHWA policy since October 1, 2010 calls for LRFR).
- Inspection date and report used, and how section loss was measured or assumed.
- Dead loads itemized into DC and DW, including current overlay thickness and whether it was field measured.
- Condition factor tied to the member condition and justified; system factor tied to a Table 6A.4.2.4-1 category; product checked against 0.85.
- Resistance factors ϕ from the LRFD Specifications for each material and effect.
- Live load models: HL-93 for design-load rating; Type 3, 3S2, 3-3, SHVs or NRL, and EV2/EV3 where required for legal-load rating; actual permit vehicles for permits.
- IM values and any reduction justified by riding surface documentation.
- Distribution factors: source (LRFD approximate or refined analysis) and multiple presence handling.
- Live load factors: 1.75/1.35 for design; ADTT source and interpolation for legal; PWR and ADTT for routine permits; trip type and traffic condition for special permits.
- Limit states checked at each level per Table 6A.4.2.2-1 and owner policy, including Service II for steel and Service III for prestressed concrete where applicable.
- Connections, floor system and nonredundant members rated.
- Controlling RF identified for each level and vehicle, and the values transferred correctly to the SNBI load rating items.
- Recommendations: posting, permit restrictions, re-rating triggers and inspection items to watch.

Part N — Summary

LRFR expresses load capacity as a rating factor: the capacity left after factored permanent loads, divided by the factored live load effect of a specified vehicle. The pieces to remember are:

- The equation: $RF = [C - \gamma_{DC}DC - \gamma_{DW}DW \pm \gamma_P P] / [\gamma_{LL}(LL + IM)]$, with $C = \phi_c \phi_s \phi_R \geq 0.85 \phi_R$ at strength and $C = f_R$ at service.
- Dead load factors 1.25 (DC) and 1.50 (DW, or 1.25 when measured) at strength, 1.00 at service.
- Live load factors: 1.75 Inventory and 1.35 Operating at Strength I; legal 1.30 to 1.45 by ADTT; routine permit 1.15 to 1.40 by ADTT and PWR at Strength II; special permit 1.10, 1.20 or 1.40 by trip type.
- Condition factors 1.00, 0.95, 0.85; system factors from 0.85 to 1.00; both strength-only, both optional by owner policy, $\phi_s = 1.0$ for shear.
- The levels run in sequence: design, then legal where needed, then permit for bridges that carry legal loads.

Always work from the current MBE edition and interim revisions adopted by the bridge owner. Load factors and tables have changed through interims (the 2013 unification of legal and SHV factors is one example), and owner policies may require more than the MBE minimum.

Key takeaways

- $RF = [C - \gamma_{DC} \cdot DC - \gamma_{DW} \cdot DW \pm \gamma_P \cdot P] / [\gamma_{LL}(LL + IM)]$; the lowest RF over all applicable limit states and effects controls.

- Strength capacity $C = \phi_c \phi_s \phi_R n$ with $\phi_c \phi_s \geq 0.85$; service capacity $C = fR$.
- Design Inventory 1.75, Operating 1.35; DC 1.25; DW 1.50, or 1.25 when the overlay thickness is field measured.
- Legal Strength I: 1.45 for unknown ADTT or $ADTT \geq 5,000$, 1.30 for $ADTT \leq 1,000$, interpolated between.
- Condition and system factors apply only at strength limit states, are optional by agency policy, and $\phi_s = 1.0$ for shear.
- $RF \times$ vehicle weight in tons gives the safe load capacity for that vehicle.

References

1. AASHTO, The Manual for Bridge Evaluation, 3rd Edition, 2018 (with interim revisions)
2. AASHTO, LRFD Bridge Design Specifications, 9th Edition, 2020

Study text only; the final quiz is taken online. Verify all references against the edition your agency has adopted.