

HL-93 Live Load, Dynamic Load Allowance and Multiple Presence

The HL-93 notional live load is the starting point for almost every highway bridge superstructure designed to the AASHTO LRFD Bridge Design Specifications. This course explains what HL-93 is and why it was built the way it was, the design truck, design tandem and design lane load, the special cases for negative moment, deflection and fatigue, the dynamic load allowance (IM) of Article 3.6.2, the multiple presence factors of Article 3.6.1.1.2, and practical rules for placing load longitudinally and transversely to get the extreme force effect. Load values were checked against public restatements of Article 3.6 in the FHWA Steel Bridge Design Handbook, the Caltrans Bridge Design Practice manual (Chapter 3, October 2022), an NCDOT LRFD seminar handout and STRUCTURE magazine. Worked example numbers are illustrative teaching values computed for this course unless a source is named. Always check the edition and interim revisions your owner has adopted, and the owner's own design manual, which may add permit or state-specific vehicles.

Learning objectives

- Describe HL-93 components
- Apply dynamic load allowance
- Apply multiple presence factors
- Place live load for maximum effect

Why a notional load?

Real truck traffic is a wide, changing population of vehicles: two-axle delivery trucks, five-axle tractor-semitrailers, specialized hauling vehicles with closely spaced axles, cranes, and overweight permit loads. No single real truck produces the worst moment and shear on every span length. The authors of the LRFD specifications therefore chose a **notional** load: a combination of vehicles and a uniform load that does not look like any one real truck, but whose force effects match the extreme effects expected from real traffic over the design life.

The FHWA Steel Bridge Design Handbook explains the history. Early drafts of the first LRFD edition considered a heavier, longer vehicle of about 57 tons (the HTL-57) to represent the trucks then on the highways. Specifying a "super-legal" truck as the design vehicle was found objectionable, so the final approach superimposed the effects of the familiar HS20 truck (or a tandem) and a uniform lane load in the same lane. The moments and shears produced by that combination are essentially equivalent to those of the more realistic 57-ton truck. The name HL-93 stands for "Highway Loading, 1993," the year the model was adopted.

The practical consequence is that HL-93 should be thought of as a calibrated *effect*, not a vehicle. You do not ask "will a truck like this cross my bridge?" You ask "is my member designed for the force effect that the calibrated model produces?" That mindset matters when engineers try to mix HL-93 with real vehicles, for example applying multiple presence factors to a permit truck. The handbook is direct that multiple presence factors should never be applied to fatigue loads or to other vehicles of relatively known weight, such as legal or permit loads.

The three HL-93 components

Article 3.6.1.2.1 defines HL-93 as a combination of:

- the **design truck or the design tandem**, whichever governs, and
- the **design lane load**.

Design truck (Article 3.6.1.2.2)

The design truck is the familiar three-axle HS20 configuration: an 8.0-kip front axle and two 32.0-kip axles, 72 kips total. The spacing from the front axle to the first 32-kip axle is 14.0 ft. The spacing between the two 32-kip axles is **variable from 14.0 ft to 30.0 ft** and is chosen to produce the extreme force effect. The transverse spacing of wheels is 6.0 ft. For simple-span moment and shear the 14-ft spacing almost always governs, because it puts the most weight closest to the critical section. The longer spacing matters in continuous spans, where spreading the heavy axles into adjacent spans can increase a negative moment or a reaction.

Design tandem (Article 3.6.1.2.3)

The design tandem is a pair of 25.0-kip axles spaced 4.0 ft apart, 50 kips total, with wheels 6.0 ft apart transversely. It represents short, heavy axle groups and governs moment on short spans. In the illustrative calculation later in this course, the tandem produces a larger simple-span moment than the truck at 30 ft but a smaller one at 60 ft.

Design lane load (Article 3.6.1.2.4)

The design lane load is **0.640 kip per linear foot**, uniformly distributed longitudinally and assumed spread over a 10.0-ft width transversely. Unlike the Standard Specifications lane loading, it acts together with the truck or tandem and carries no associated concentrated loads. It may be broken into patches to get the extreme effect; for example, in a continuous girder it is placed only in the spans that contribute to the effect being sought.

Three rules apply to the combination. First, the truck or tandem and the lane load act in the same design lane at the same time. Second, axles that do not contribute to the extreme effect are neglected; you do not have to keep the front axle on the bridge if it reduces the effect. Third, dynamic load allowance applies to the truck or tandem but **not** to the lane load, as covered later in this course.

Design lanes and where the load goes

Live load is placed in **design lanes**, not the striped traffic lanes. Article 3.6.1.1.1 sets the number of design lanes as the integer part of $w/12.0$, where w is the clear roadway width in feet between curbs or barriers. Each design lane is 12.0 ft wide. Roadways from 20 to 24 ft wide get two design lanes, each one half the roadway width. Future changes, such as removing a median or restriping, should be considered where they are planned or likely.

Inside its design lane, the 10-ft loaded width of the truck, tandem or lane load is placed for maximum effect. Article 3.6.1.3.1 sets limits on how close the wheels can get to the edge. For deck overhang design, the center of the wheel is placed 1.0 ft from the face of the curb or railing. For all other components, the center of the wheel is placed 2.0 ft from the edge of the design lane. These rules matter most for the exterior girder and the deck overhang, where pushing the wheel line outward increases the effect.

Not every lane has to be loaded. You load the number of lanes, and the positions within them, that produce the extreme effect, taking into account the multiple presence factor for that number of lanes. Sometimes one lane loaded with the 1.20 factor governs; sometimes all lanes loaded with a smaller factor governs. Both must be checked when using the lever rule or a refined analysis.

Special load cases in Article 3.6.1.3 and 3.6.1.4

The basic HL-93 combination (truck or tandem, plus lane) is the default, but the specification adds several cases that apply only to particular effects. Missing one of them is a common source of review comments, so it is worth treating them as a checklist.

Negative moment and interior pier reactions

For negative moment between points of permanent-load contraflexure, and for reactions at interior piers, Article 3.6.1.3.1 adds a case of **90 percent of the effect of two design trucks**, spaced a minimum of 50 ft between the lead axle of one truck and the rear axle of the other, combined with **90 percent of the effect of the design lane load**. In this case the distance between the two 32-kip axles of each truck is taken as 14 ft. The NCDOT seminar handout and the Caltrans Bridge Design Practice manual both show this case as a separate loading diagram, and Caltrans notes that in its four standard HL-93 cases, the two-truck case is used only for negative moments, associated shears and bent reactions.

Why only 90 percent? Two heavy trucks closely following each other in the same lane over a pier is a plausible event in congested traffic, but the probability that both are at their heaviest at the same time is lower than for a single truck. The 0.90 factor reflects that. Note that the 50-ft minimum is a *minimum*: the trucks are positioned, subject to that limit, to maximize the effect, which usually means one truck in each span adjacent to the pier.

The phrase "between points of permanent-load contraflexure" is important. The two-truck case is not applied everywhere in a continuous girder, only in the region where dead load produces negative moment. Software that applies it across the whole span is conservative in positive moment regions but not required by the specification there.

Deflection

Where the owner invokes the optional live load deflection criteria of Article 2.5.2.6.2, Article 3.6.1.3.2 sets the deflection load as the larger of:

- the design truck alone, or
- 25 percent of the design truck taken together with the design lane load.

The FHWA NHI LRFD superstructures reference manual summarizes the related practice: all design lanes are loaded, dynamic load allowance is included, multiple presence factors are included, and the number and position of loaded lanes is selected for the extreme effect. Many owners also assume that all girders deflect equally, which amounts to sharing the lane loads evenly among the girders. Whether deflection limits apply at all, and which ratio (for example span/800 for vehicular load), is an owner decision, so record it in the design criteria.

Fatigue

Article 3.6.1.4.1 defines the fatigue load as **one design truck** (or axles of it) with a **constant 30.0-ft spacing** between the 32-kip axles. The longer fixed spacing was chosen because it better represents the average heavy truck for cumulative damage, rather than an extreme. The fatigue truck is placed in one lane only, the dynamic load allowance is 15 percent, and multiple

presence factors are not applied. Under the current tables reviewed in BR-D01, the load factor is 1.75 for Fatigue I (infinite life) and 0.80 for Fatigue II (finite life).

A practical trap follows from that rule. The empirical distribution factor equations of Article 4.6.2.2 for one loaded lane already include the 1.20 multiple presence factor. When those single-lane factors are used for fatigue, Article 3.6.1.1.2 requires the 1.20 to be removed, which is done by dividing the force effect by 1.20. Caltrans illustrates the same principle with its own fatigue cases: a single HL-93 truck with 30-ft rear spacing run across the bridge by itself, and a P9 permit truck by itself, each with 15 percent dynamic load allowance.

Deck and wheel loads

For deck design, Article 3.6.1.3.3 directs that, where the approximate strip method is used, slabs and decks be designed for the axles of the design truck or design tandem; the lane load is not needed for most deck strips spanning transversely. Article 3.6.1.2.5 assumes the tire contact area of a wheel with one or two tires as a single rectangle 20.0 in wide and 10.0 in long, with uniform tire pressure. That footprint matters for punching shear, for local effects in orthotropic and grid decks, and for refined deck models.

Dynamic load allowance (IM)

A moving truck produces larger force effects than the same truck parked on the bridge. Road surface roughness, joints, approach slab settlement and the truck's own suspension make the axle forces oscillate, and the bridge responds dynamically. The LRFD specification handles this with a simple increment on the static effect of the vehicle, called the **dynamic load allowance**, IM, in Article 3.6.2. Older engineers will know it as "impact," and the Standard Specifications computed it with a span-dependent formula, $I = 50/(L + 125) \leq 0.30$. LRFD replaced that formula with fixed percentages.

Table 3.6.2.1-1

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

The static effect of the design truck or tandem is multiplied by (1 + IM/100). For a strength check of a girder, that is 1.33 times the truck or tandem effect. The Caltrans example writes the combined effect as $LL + IM = 1.33 \text{ (truck moment)} + \text{(lane moment)}$, which captures both rules at once: the 33 percent is applied, and it is applied only to the vehicle part.

What IM does not apply to

- **The design lane load.** The FHWA Steel Bridge Design Handbook states that IM applies only to the design trucks, design tandems and the fatigue truck, and should not be applied to the uniformly distributed lane load. STRUCTURE magazine makes the same point.
- **Pedestrian loads.** Article 3.6.2.1 excludes them.
- **Centrifugal and braking forces.** These are horizontal effects derived from the vehicle weight and are not increased by IM.
- **Some substructure and buried elements.** Article 3.6.2.1 notes that IM need not be applied to retaining walls not subject to vertical reactions from the superstructure, or to foundation components entirely below ground level.

Buried components and wood

For culverts and other buried structures, Article 3.6.2.2 reduces IM with depth of cover: $IM = 33(1.0 - 0.125 D_E) \geq 0$ percent, where D_E is the minimum depth of earth cover above the structure in feet. At 8 ft of cover the allowance reaches zero. This follows naturally from the fact that soil damps the dynamic effect of the wheel. Article 3.6.2.3 permits IM for wood bridges and wood components to be taken as 50 percent of the values in Table 3.6.2.1-1, reflecting wood's damping and the reduced dynamic response observed in timber bridges. Both are good examples of why you should read the subarticles rather than assume 33 percent everywhere.

Why fixed values?

The dynamic response of a bridge depends mostly on the roughness of the riding surface, especially at joints and approach slabs, and on how the vehicle suspension interacts with the bridge, rather than on span length alone. LRFD therefore moved from the span-based Standard Specifications formula to fixed values, with the commentary to Article 3.6.2.1 discussing the basis. Because IM is applied only to the truck or tandem, and the lane load carries no increment, the effective dynamic increment on the total HL-93 effect is smaller than 33 percent and falls as span length grows and the lane load share increases. The 75 percent for deck joints reflects the hammering that joints take from wheel impacts at a discontinuity. The 15 percent for fatigue reflects that fatigue is about typical, repeated response rather than a single extreme event.

Permit vehicles and owners' variations

Owners may set their own dynamic allowances for owner-specified vehicles. The Caltrans Bridge Design Practice manual, for example, uses 25 percent for its permit truck in its worked example ($LL + IM = 1.25$ times the permit static moment), compared with 33 percent for HL-93. When load rating, the AASHTO Manual for Bridge Evaluation has its own rules for IM, including possible reductions based on approach and deck riding surface conditions; those are covered in the load rating courses (BR-L01 to BR-L06) and should not be confused with design values.

Common errors with IM

- Applying 1.33 to the total HL-93 effect, including the lane load. This overstates the effect, by 0.33 times the lane load effect; in this course's illustrative simple-span numbers that is roughly 5 to 9 percent of the correct total for 30- to 100-ft spans.
- Applying 33 percent to fatigue checks instead of 15 percent.
- Forgetting the 75 percent for joint and joint-anchorage design.
- Using the full 33 percent on a deeply buried culvert where Article 3.6.2.2 would reduce it or eliminate it.
- Applying IM to braking or centrifugal force.

Multiple presence factors

If a bridge has three design lanes, is it realistic to put a fully loaded HL-93 in every lane at the same time? Sometimes, on a congested urban viaduct, partly. Usually, no. Article 3.6.1.1.2 handles this with the **multiple presence factor**, m , applied to the live load effect according to the number of loaded lanes.

Number of loaded lanes	m
1	1.20
2	1.00

3	0.85
More than 3	0.65

The values above appear in Table 3.6.1.1.2-1 and are restated in the Caltrans Bridge Design Practice manual (Table 3.4-6).

Why one lane gets 1.20

The factor of 1.00 for two lanes is the anchor point. The FHWA Steel Bridge Design Handbook explains that the calibration of the notional load was normalized to the occurrence of two side-by-side, fully correlated (identical) vehicles. A single lane carrying a single truck is more likely to see a heavier-than-modeled truck than two lanes are to see two such trucks simultaneously, so the one-lane factor is larger than 1.0. The handbook notes that the 1.20 factor should be used where a single design truck or tandem governs, such as in overhangs and decks. Three or more lanes get progressively lower factors because the chance that every lane holds its heaviest truck at the same instant drops quickly.

STRUCTURE magazine's history of the live load model describes the two traffic situations considered in developing these factors: random traffic at highway speed, with the site-average number of trucks distributed across the structure and separated by cars, and traffic jams, with trucks moving slowly, mostly in one lane, while cars use the others. Truck behavior was taken from survey data on Michigan interstate highways.

How m is applied in practice

- **Approximate distribution factors.** The empirical live load distribution factor equations in Article 4.6.2.2 (covered in BR-D03) already include multiple presence. Do not apply m again when using them.
- **Lever rule and statical method.** When distribution is computed by the lever rule, the rigid-section method for exterior girders, or any hand method that places wheels explicitly, m must be applied by the engineer, because the calculation does not include it.
- **Refined analysis.** Grillage, plate and finite element models place lanes explicitly, so the analyst checks one lane loaded with 1.20, two lanes with 1.00, and so on, and keeps the governing result for each element.
- **Fatigue.** Multiple presence is not applied to fatigue, and the 1.20 built into single-lane distribution factors is divided out, as described earlier.
- **Known-weight vehicles.** The FHWA handbook is clear that m should never be applied to legal or permit loads or to other vehicles of relatively known weight. Load rating rules in the Manual for Bridge Evaluation govern those cases.

Pedestrian loads and multiple presence

Article 3.6.1.6 specifies a pedestrian load of 0.075 ksf on sidewalks wider than 2.0 ft, considered simultaneously with the vehicular design live load in the vehicle lane. The FHWA handbook restates the 75 psf value. For the purpose of determining the multiple presence factor, Article 3.6.1.1.2 permits a loaded pedestrian sidewalk to be taken as one loaded lane. That means a bridge with one vehicular lane loaded plus a loaded sidewalk is treated as two loaded lanes, with $m = 1.00$, in that check. Pedestrian load also carries no dynamic load allowance.

Worked comparison (illustrative)

Suppose, for teaching purposes only, a refined model of a girder gives a live load effect of 400 units with one lane loaded, 700 units with two lanes loaded, and 880 units with three lanes loaded, before multiple presence. Applying m gives:

- One lane: $1.20 \times 400 = 480$

- Two lanes: $1.00 \times 700 = 700$
- Three lanes: $0.85 \times 880 = 748$

In this illustrative case three lanes governs. If the three-lane effect had been 800 units, $0.85 \times 800 = 680$ would have been less than the two-lane value, and two lanes would have governed. The lesson is that you cannot assume either "all lanes loaded" or "one lane loaded" governs; the specification asks for the extreme, so each case is evaluated.

Worked example: simple-span HL-93 moment and shear (illustrative)

The numbers in this section were computed for this course by moving the design truck and design tandem across simple spans in small steps and recording the largest moment anywhere in the span. They are illustrative teaching values per design lane, before distribution to girders and before load factors. They are close to the values in published HS20 moment tables for the truck alone, but you should compute or look up your own values with your software for design.

Step 1: vehicle moments

Span	Design truck max moment	Design tandem max moment	Governing vehicle
30 ft	about 282 kip-ft	about 327 kip-ft	Tandem
60 ft	about 806 kip-ft	about 701 kip-ft	Truck
100 ft	about 1,524 kip-ft	about 1,200 kip-ft	Truck

On short spans the full 72-kip truck cannot fit on the span well; at 30 ft the axles that would add moment fall off the span or near the supports, and the compact 50-kip tandem governs. By 60 ft the truck clearly governs. This crossover is one reason the tandem is part of HL-93.

Step 2: where the truck goes

For a group of moving concentrated loads on a simple span, the maximum moment occurs under one of the loads when the centerline of the span bisects the distance between that load and the resultant of all the loads on the span. For the design truck with 14-ft spacings, the resultant of the 72 kips lies 18.67 ft behind the front axle ($(32 \times 14 + 32 \times 28)/72$), which is 4.67 ft from the center axle toward the rear axle. Placing the center (32-kip) axle 2.33 ft from midspan, with the resultant 2.33 ft on the other side, gives the maximum moment, which occurs under that axle. This is the classic rule from structural analysis texts, and it is a good hand check on software output.

Step 3: lane load moment

The lane load moment for a simple span is $wL^2/8$ with $w = 0.64$ klf:

- 30 ft: $0.64 \times 30^2 / 8 = 72$ kip-ft
- 60 ft: $0.64 \times 60^2 / 8 = 288$ kip-ft
- 100 ft: $0.64 \times 100^2 / 8 = 800$ kip-ft

Strictly, the lane load maximum is at midspan, while the truck maximum is 2.33 ft away. Adding the two maxima is a slightly conservative and very common simplification; a program that sums effects at each point will give a marginally lower combined value.

Step 4: combine with IM

LL + IM per lane = $1.33 \times (\text{governing vehicle}) + \text{lane}$:

- 30 ft: $1.33 \times 327 + 72 \approx 507$ kip-ft
- 60 ft: $1.33 \times 806 + 288 \approx 1,360$ kip-ft
- 100 ft: $1.33 \times 1,524 + 800 \approx 2,827$ kip-ft

Notice how the lane load share grows with span: about 14 percent of the total at 30 ft, about 21 percent at 60 ft and about 28 percent at 100 ft in these illustrative values. On long spans the lane load becomes a large part of the design live load.

Step 5: shear at the support

For end shear on the 60-ft span, place the rear 32-kip axle at the support with the truck heading into the span: $V = 32 + 32(46/60) + 8(32/60) \approx 32 + 24.5 + 4.3 = 60.8$ kips. The tandem with one axle at the support gives $25 + 25(56/60) \approx 48.3$ kips, so the truck governs. The lane load end shear is $wL/2 = 0.64 \times 60 / 2 = 19.2$ kips. LL + IM = $1.33 \times 60.8 + 19.2 \approx 100.1$ kips per lane.

Step 6: what comes next

These per-lane values are then multiplied by a girder distribution factor (BR-D03), which includes multiple presence when the empirical equations are used. For a Strength I check the result is multiplied by the live load factor of 1.75 and by the load modifier η , and added to the factored dead load effects as described in BR-D01. For example, if an illustrative distribution factor of 0.60 lanes per girder applied to the 60-ft span, the Strength I live load moment per girder would be $1.75 \times 0.60 \times 1,360 \approx 1,428$ kip-ft before η . Again, these are teaching numbers, not a design.

Placing live load for maximum effect: influence lines

Article 3.6.1.3.1 asks for the extreme force effect. For anything beyond a single simple span, the reliable way to find it is an **influence line**: a plot of the force effect at one point (a moment, a shear, a reaction) as a unit load moves across the structure. Once you have the influence line, placing HL-93 becomes a set of simple rules.

Rules for each component

- **Lane load.** Place the 0.64 klf only where the influence line has the sign you want. For maximum positive moment in an interior span of a continuous girder, that usually means loading the span itself and alternate spans; for maximum negative moment over a pier, the two adjacent spans and then alternate spans beyond. The lane load may be discontinuous; it is "patch loaded" over the regions that add to the effect.
- **Truck or tandem.** Place the heaviest axles at or near the peak ordinate of the influence line, then adjust the variable 14-to-30-ft rear axle spacing of the truck to put the rear axle over another high ordinate if one exists. Drop any axle that sits on a region of opposite sign, because axles that do not contribute are neglected.
- **Two-truck case.** For negative moment between points of permanent-load contraflexure and for interior pier reactions, also place two trucks (90 percent each, with 14-ft rear spacing), with at least 50 ft between the lead axle of one and the rear axle of the other, typically one in each span adjacent to the pier, plus 90 percent of the lane load.
- **Only one vehicle per lane** except in the two-truck case. The Caltrans manual puts this plainly: when loading the superstructure with HL-93, only one vehicle per lane is placed on the bridge at a time, except for the negative moment cases.

Why the variable spacing matters in continuous spans

In a two-span continuous girder, the influence line for moment over the interior pier is negative in both spans, with peaks somewhere near the middle of each span. A truck with 14-ft rear spacing concentrates its 64 kips of heavy axles in one span. Stretching the rear spacing toward 30 ft may put one heavy axle near the peak of the first span and the other closer to the peak in the second. Software that does not vary the spacing can understate the negative moment and the pier reaction for the single-truck case. When you check a program's output by hand, check the reported axle spacing as well as the value.

Shear and reactions

For shear at a section, the influence line has a jump at the section. Maximum positive shear just to the right of a point usually comes from placing the heaviest axle just to the right of the section and loading the lane load only on the side that adds to the shear. For reactions at piers, the two-truck case often governs bearing and pier cap design in continuous bridges, which is why the specification includes interior pier reactions in Article 3.6.1.3.1.

Transverse placement

Transversely, the logic is similar but with lanes rather than axles. Design lanes, each 12 ft, are positioned across the roadway; within each, the 10-ft load width is moved to produce the extreme effect, subject to the wheel-to-edge limits (1.0 ft from the curb or railing face for overhangs, 2.0 ft from the lane edge for other components). For an exterior girder, the governing case is often one lane placed as far out as allowed with $m = 1.20$, but checks with more lanes loaded are still needed. Refined analysis programs automate this by moving lanes in small increments; check that the program honors the 2-ft rule and does not let a lane hang over the barrier.

Hand checks that catch software errors

- For a simple span over about 40 ft, the truck moment per lane should be close to a published HS20 moment table value; if it is far off, check units, axle loads and spacing.
- The lane load moment on a simple span should equal $wL^2/8$ exactly; a different value suggests the lane load is being applied with IM or with the wrong width.
- A continuous girder's negative moment should increase when the two-truck case is switched on, at least near the pier; if it does not, check that the case is being run.
- Fatigue truck results should show a fixed 30-ft spacing and 1.15 dynamic factor.

HL-93 compared with HS20-44, and related vehicle forces

Many engineers still meet HS20-44 when they check older bridges, read old plans or load rate. Understanding the differences helps avoid mixing the two systems.

What changed from the Standard Specifications

- **Truck.** The HL-93 design truck has the same axle weights and spacings as the HS20-44 truck. The difference is what it is combined with.
- **Lane load.** Under the Standard Specifications, the HS20 lane loading was 0.64 klf *plus* a concentrated load (18 kips for moment, 26 kips for shear), and it was used *instead of* the truck when it governed, typically on longer spans. Under LRFD, the 0.64 klf lane load acts *together with* the truck or tandem, without concentrated loads.
- **Tandem.** The 25-kip tandem is similar to the Alternate Military Loading of the Standard Specifications (two 24-kip axles 4 ft apart), as the FHWA handbook notes.

- **Impact.** The span-dependent formula $50/(L + 125)$, capped at 30 percent and applied to truck and lane loading, was replaced by fixed IM values applied only to the truck or tandem.
- **Multiple presence.** The Standard Specifications used reduction factors of 1.0 for one or two lanes, 0.90 for three lanes and 0.75 for four or more. LRFD introduced the 1.20 factor for one lane and different values for more lanes, consistent with its calibration.

Because both the load model and the factors changed, an HL-93 result cannot be compared to an HS20 result by ratio alone. In general HL-93 produces larger force effects than HS20-44, especially on longer spans where the concurrent lane load adds substantially to the truck effect.

Braking force (Article 3.6.4)

The braking force is taken as the greater of: 25 percent of the axle weights of the design truck or design tandem; or 5 percent of the design truck plus lane load, or 5 percent of the design tandem plus lane load. It is placed in all design lanes that are considered loaded and carry traffic headed in the same direction, assumed to act horizontally at a distance of 6.0 ft above the roadway surface in either longitudinal direction, to produce the extreme effect. Multiple presence factors apply. Braking force matters for bearings, expansion joints, piers and abutments, particularly on long continuous units where the longitudinal force goes to a few fixed bearings.

Centrifugal force (Article 3.6.3)

On horizontally curved bridges, the centrifugal force is the axle weight of the design truck or tandem times a factor $C = f v^2/(g R)$, where v is the highway design speed, g is the gravitational acceleration, R is the radius of curvature of the traffic lane, and f is 4/3 for load combinations other than fatigue and 1.0 for fatigue. The force acts horizontally at 6.0 ft above the roadway surface, and multiple presence factors apply. Like braking, it is a horizontal effect of the vehicle and is not increased by IM.

HL-93 in load rating

HL-93 is also the basis of the *design load rating* in the AASHTO Manual for Bridge Evaluation, the first level of LRFR evaluation. At the inventory level the live load factor is 1.75 and at the operating level it is 1.35, matching the reliability targets associated with design. Legal load and permit load ratings then use real vehicles with their own factors. If you are coming from the load rating courses, note that the HL-93 model, the 33 percent IM and the multiple presence factors are design-level assumptions; the rating manual sets its own rules for legal and permit vehicles.

Putting it into practice: a live load checklist

The rules in Article 3.6 are short, but they interact. A written live load section in the project design criteria, reviewed before analysis starts, prevents most of the errors that show up in independent checks. The checklist below is a practical summary of this course, not a substitute for the specification text or the owner's manual.

1. Define the vehicles

- HL-93: design truck (8, 32, 32 kips; 14 ft; 14 to 30 ft) or design tandem (25, 25 kips; 4 ft), plus 0.640 klf lane load over 10 ft.
- Two-truck negative moment and interior pier reaction case: 90 percent of two trucks (14-ft rear spacing, at least 50 ft apart) plus 90 percent of lane load.
- Fatigue truck: one design truck with 30-ft rear spacing.

- Deflection load, if the owner applies deflection limits: the larger of the truck alone or 25 percent of the truck plus the lane load.
- Any owner-specified permit or design vehicles, with their own dynamic allowance and load combination (Strength II for owner-specified special design or permit vehicles, as discussed in BR-D01).

2. Define the lanes

- Clear roadway width between barriers and the number of design lanes, $INT(w/12)$, with the 20-to-24-ft rule.
- Any planned future widening, median removal or restriping that changes the clear width.
- Wheel limits: 1.0 ft from the curb or railing face for overhangs, 2.0 ft from the design lane edge for everything else.
- Sidewalks: pedestrian load of 0.075 ksf if wider than 2.0 ft, and whether a sidewalk counts as a loaded lane for multiple presence.

3. Define the factors

- IM: 33 percent for most components and limit states, 15 percent for fatigue, 75 percent for deck joints, reduced for buried components by depth of cover and permitted reduction for wood, none on the lane load or pedestrian load.
- Multiple presence: 1.20, 1.00, 0.85, 0.65; included in empirical distribution factors; applied explicitly in lever rule and refined analysis; not used for fatigue; divided out of single-lane factors for fatigue.
- Load factors and modifiers from Tables 3.4.1-1 and 3.4.1-2 per the edition adopted.

4. Define the analysis method

- Approximate distribution factors (BR-D03) or refined analysis, and the reason for the choice.
- For line girder programs: verify the axle spacing used, the two-truck case and the treatment of the lane load in each span.
- For refined models: verify the lane positioning increment, the multiple presence handling and the wheel-edge limits.

5. Hand check a few numbers

Pick one positive moment, one negative moment and one end shear and reproduce them by hand with the influence line rules in this course. The illustrative simple-span values here (about 1,360 kip-ft LL+IM per lane at 60 ft, about 100 kips end shear) give a sense of scale. If a program result is wildly different for a similar span, find out why before relying on it.

Frequently missed items

1. IM applied to the lane load.
2. Two-truck case omitted, or applied outside the negative moment region only.
3. Fatigue run with 14-ft spacing, 33 percent IM or multiple presence.
4. 1.20 not divided out of single-lane distribution factors for fatigue.
5. Multiple presence applied twice, once in the distribution factor and again in the analysis.
6. Multiple presence applied to a permit truck.
7. Overhang checks run with the 2-ft lane-edge limit instead of the 1-ft curb-face limit.
8. Number of lanes taken from striping rather than from clear roadway width.

Summary and review

HL-93 is a calibrated notional model: the design truck or the design tandem, superimposed with the 0.640 klf design lane load in the same 12-ft design lane, producing force effects intended to represent real traffic over a 75-year design life. Around that core, Article 3.6 adds special cases that apply to particular effects: the 90-percent two-truck case for negative moment and interior pier reactions, the truck-or-25-percent-plus-lane case for deflection, and the single 30-ft-spacing truck for fatigue.

Two modifiers adjust the static vehicle effect. The dynamic load allowance increases the truck or tandem effect by 33 percent for most checks, 15 percent for fatigue and 75 percent for deck joints, never touching the lane load or pedestrian load, and decreasing for buried structures and wood. The multiple presence factor adjusts for the number of lanes loaded, 1.20 for one lane down to 0.65 for more than three, and is already built into the empirical distribution factor equations, which is why its handling must be tracked carefully through fatigue and refined analysis.

Finally, load is placed for the extreme effect: longitudinally with influence lines, dropping axles that do not help and varying the truck's rear axle spacing; transversely within design lanes and edge limits, checking different numbers of loaded lanes. Horizontal vehicle effects, braking and centrifugal force, come from the same vehicles but follow their own rules. The next course, BR-D03, takes the per-lane effects computed here and distributes them to individual girders.

Self-check questions

- On a 30-ft simple span, why does the tandem govern moment while the truck governs at 60 ft?
- Which of these receive the 33 percent dynamic load allowance: the design truck, the design lane load, the pedestrian load, the braking force? (Only the design truck.)
- Over a pier in a three-span continuous unit, which HL-93 cases must be run for negative moment, and what rear axle spacing does each truck use in the two-truck case?
- You used the lever rule for an exterior girder with one lane loaded. Did you apply $m = 1.20$? Would you apply it again if you had used the empirical equation instead?
- Your fatigue check uses a single-lane empirical distribution factor. What do you do with the 1.20 built into it?

If you can answer each of these from memory, with the article number, you are ready for the quiz.

Key takeaways

- HL-93 is a notional load: its force effects were calibrated to represent real traffic, not any one real truck.
- HL-93 = (design truck OR design tandem) + design lane load, in the same lane (Article 3.6.1.2.1).
- Design truck: 8.0, 32.0 and 32.0 kips; 14.0 ft front spacing; 14.0 to 30.0 ft rear spacing; 6.0 ft wheel gage.
- Design tandem: two 25.0-kip axles 4.0 ft apart. Design lane load: 0.640 klf over a 10-ft width, with no concentrated loads.
- Negative moment and interior pier reactions also check 90% of two design trucks at least 50 ft apart plus 90% of the lane load.
- IM: 75% for deck joints, 15% for fatigue and fracture, 33% for all other limit states; never on the lane load or pedestrian load.
- Multiple presence: 1.20 / 1.00 / 0.85 / 0.65 for 1 / 2 / 3 / more than 3 loaded lanes; not for fatigue, and not for vehicles of known weight.
- Design lanes = $\text{INT}(w/12)$; wheel centers 1.0 ft from curb face for overhangs and 2.0 ft from the lane edge otherwise.

References

1. AASHTO, LRFD Bridge Design Specifications, 9th Edition, 2020
2. Federal Highway Administration, Steel Bridge Design Handbook, Volume 7: Loads and Load Combinations, FHWA (rosap.ntrl.bts.gov/view/dot/42714)
3. California Department of Transportation, Bridge Design Practice, Chapter 3: Loads and Load Combinations, October 2022
4. North Carolina DOT Structures Seminar handout, LRFD, The USA's Innovative Bridge Design Specifications
5. STRUCTURE magazine, AASHTO Vehicle Live Loading (structuremag.org)
6. Federal Highway Administration, Load and Resistance Factor Design (LRFD) for Highway Bridge Superstructures Reference Manual, FHWA-NHI-15-047

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