12. Loads and Load Factors

12.1. General

12.1.1. Load Definitions

Reference: LRFD Article 3.3.2

Permanent Loads

Reference: LRFD Article 3.5

Permanent loads are loads that are always present in or on the bridge and do not change in magnitude during the life of the bridge.

Transient Loads

Transient loads are loads that are not always present in or on the bridge or change in magnitude during the life of the bridge.

12.1.2. Limit States

Reference: LRFD Article 1.3.2

The *LRFD Specifications* group the traditional design criteria together within generalized groups of design criteria termed "limit states." The *LRFD Specifications* assign multiple load combinations to the various limit states.

Basic LRFD Equation

Design the components and connections of a bridge to satisfy the basic LRFD equation for all limit states:

$$\sum \eta_i \gamma_i Q_i \leq \phi R_n \quad \textit{(LRFD Eq.1.3.2.1-1)}$$

Where:

- γ_i = load factor
- Q_i = load or force effect
- ϕ = resistance factor
- R_n = nominal resistance
- η_i = load modifier as defined in LRFD Equations 1.3.2.1-2 and 1.3.2.1-3

The left-hand side of LRFD Equation 1.3.2.1-1 is the sum of the factored load (force) effects acting on a component; the right-hand side is the factored nominal resistance of the component for the effects. Consider all applicable limit-state load combinations for the Equation. Similarly, the Equation is applicable to both superstructures and substructures.

For the strength limit states, the *LRFD Specifications* are a hybrid design code in that, for the most part, the force effect on the left-hand side of the LRFD Equation is based upon elastic structural response, while resistance on the right-hand side of the Equation is determined predominantly by applying inelastic response principles. The *LRFD Specifications* have adopted the hybrid nature of strength design on the assumption that the inelastic component of structural performance will always remain relatively small because of non-critical redistribution of force effects. Ensure this non-criticality by providing adequate redundancy and ductility of the structures.

Load Modifier

The load modifier η_I relates the factors η_D, η_R, and η_I to ductility, redundancy, and operational importance. The location of η_I on the load side of the LRFD Equation may appear counterintuitive because it appears to relate more to resistance than to load. η_I is on the load side for a logistical reason. When η_I modifies a maximum load factor, it is the product of the factors as indicated in LRFD Equation 1.3.2.1-2; when η_I modifies a minimum load factor, it is the reciprocal of the product as indicated in LRFD Equation 1.3.2.1-3. These factors are somewhat arbitrary; their significance is in their presence in the *LRFD Specifications* and not necessarily in the accuracy of their magnitude. The LRFD factors reflect the desire to promote redundant and ductile bridges.

In general, use η_I values of 1.00 for all limit states, because bridges designed in accordance with this *Manual* will demonstrate traditional levels of redundancy and ductility. Rather than penalize less redundant or less ductile bridges, the DOT&PF does not encourage such bridges. DOT&PF may on a case-by-case basis designate a bridge to be of special operational importance and specify an appropriate value of η_I. For structural systems with only two longitudinal main members (e.g., two-girder/truss/arch bridges), η_I shall be taken as 1.20 for the girder/truss/arch.

Do not confuse the load modifier, η_I, accounting for importance of LRFD Article 1.3.5 with the categories of critical or essential bridges for seismic design of Article 3.1 of the *Guide Specifications for LRFD Seismic Bridge Design*. Use 1.0 for the importance load modifier used in the basic LRFD Equation, but use the critical or essential category to determine the minimum seismic requirements.

12.1.3. Load Factors and Combinations

Reference: LRFD Article 3.4.1

LRFD Table 3.4.1-1 provides the load factors for all of the load combinations of the *LRFD Specifications*.

Strength Load Combinations

The *LRFD Specifications* have calibrated the load factors for the Strength load combinations based upon structural reliability theory, which represents the uncertainty of their associated loads. The following simplifies the significance of the Strength load combinations, and it provides guidance on which Strength limit states are applicable to the bridge under design:

1. **Strength I Load Combination**. This load combination represents random traffic and the heaviest truck to cross the bridge in its 75-year design life. During this live-load event, a significant wind is not considered probable.
2. **Strength II Load Combination**. In the *LRFD Specifications*, this load combination represents an owner-specified permit load model. This live-load event has less uncertainty than random traffic and, thus, a lower live-load load factor. DOT&PF does not specify a design permit load. Therefore, this load combination is not applicable in Alaska.
3. **Strength III Load Combination**. This load combination represents the most severe wind during the bridge's 75-year design life. During this event, assume that no significant live load crosses the bridge.
4. **Strength IV Load Combination**. This load combination represents an extra safeguard for bridge superstructures where the unfactored dead load exceeds seven times the unfactored live load. Thus, the only significant load factor is the 1.25 dead-load maximum load factor. For additional safety, and based on engineering judgment, the *LRFD Specifications* has arbitrarily increased the load factor for DC to 1.5. This load combination typically governs only for longer spans, greater than approximately 200 feet in length. Thus, this load combination will only be necessary in relatively rare cases.
5. **Strength V Load Combination**. This load combination represents the simultaneous occurrence of a "normal" live-load event and a "55-mph" wind event with load factors of 1.35 and 0.4, respectively.

For components not traditionally governed by wind force effects, the Strength III and Strength V load combinations do not govern. Generally, the Strength I load combination governs for a typical multi-girder highway overpass.

Service Load Combinations

Unlike the Strength load combinations, the Service load combinations are material dependent.

Extreme-Event Load Combinations

The Extreme-Event limit states differ from the Strength limit states, because the event for which the bridge and its components are designed has a greater return period than the 75-year design life of the bridge (or a much lower frequency of occurrence than the loads of the Strength limit state).

Fatigue-and-Fracture Load Combination

The Fatigue-and-Fracture load combination, although strictly applicable to all types of superstructures, only affects the steel elements, components, and connections of a limited number of steel superstructures. Chapter 15 discusses fatigue and fracture for steel.

Application of Multiple-Valued Load Factors

Maximum and Minimum Permanent-Load Load Factors. In LRFD Table 3.4.1-1, the variable γ_P represents load factors for all of the permanent loads, shown in the first column of load factors. This variable reflects that the Strength and Extreme-Event limit state load factors for the various permanent loads are not single constants, but they can have one of two extreme values. LRFD Table 3.4.1-2 provides these two extreme values for the various permanent load factors, maximum, and minimum. These maximum and minimum values do not represent a usable range of values. Either the maximum or the minimum value shall apply, not both. Further, in a single load-combination evaluation, the bridge engineer applies either the maximum or the minimum value uniformly to the permanent load, not a combination of the two values. Permanent loads are always present on the bridge, but the nature of uncertainty is that the actual loads may be more or less than the nominal specified design values. Therefore, maximum and minimum load factors reflect this uncertainty.

Select the appropriate maximum or minimum permanent-load load factors to produce the more critical load effect. For example, in continuous superstructures with relatively short-end spans, transient live load in the end span causes the bearing to be more compressed, while transient live load in the second span causes the bearing to be less compressed and perhaps lift up. To check the maximum compression force in the bearing, place the live load in the end span and use the maximum DC load factor of 1.25 for all spans. To check possible uplift of the bearing, place the live load in the second span and use the minimum DC load factor of 0.90 for all spans.

Superstructure design uses the maximum permanent-load load factors almost exclusively; the most common exception is uplift of a bearing as discussed above.

With the use of maximum and minimum load factors, the *LRFD Specifications* have generalized load situations such as uplift where a permanent load (in this case a dead load) reduces the overall force effect (in this case a reaction). Select permanent load factors, either maximum or minimum, for each load combination to produce extreme force effects.

Substructure design routinely uses the maximum and minimum permanent-load load factors from LRFD Table 3.4.1-2. An illustrative yet simple example is a spread footing supporting a cantilever retaining wall. When checking bearing, factor up the weight of the soil (EV) over the heel by the maximum load factor, 1.35, because greater EV increases the bearing pressure, q_{ult}, making the limit state more critical. When checking sliding, factor EV by the minimum load factor, 1.00, because lesser EV decreases the resistance to sliding, Q_τ, again making the limit state more critical. Foundation and substructure design requires the application of these maximum and minimum load factors.

12.2. Permanent Loads

12.2.1. General

Reference: LRFD Article 3.5

The *LRFD Specifications* specify seven components of permanent loads, which either are direct gravity loads or caused by gravity loads.

Consider the primary forces from prestressing to be part of the resistance of a component. Omit these from the list of permanent loads in Section 3 of the *LRFD Specifications*. However, when designing anchorages for prestressing tendons, the prestressing force is the only load effect, and appears on the load side of the LRFD Equation. The permanent load EL includes secondary forces from pre-tensioning or post-tensioning. As specified in LRFD Table 3.4.1-2, use a constant load factor of 1.0 for both maximum and minimum load factors for EL.

12.2.2. Superstructure Gravity Loads (DC and DW)

Include a uniform load of 50 psf to account for a wearing surface over the entire deck area between the face of rails or sidewalks. Although not normally permitted in new designs, where steel stay-in-place formwork is used, account for the steel form weight and any additional concrete in the flutes of the formwork.

12.2.3. Distribution of Gravity Loads to Girders

Reference: LRFD Article 4.6.2.2.1

Superimposed dead loads (e.g., curbs, barriers, sidewalks, parapets, railings, wearing surfaces) may be distributed equally to all girders as traditionally specified by AASHTO. For wider bridges with more than six girders, assume that the superimposed dead loads of sidewalks, parapets, or railings are carried by the three girders immediately under and adjacent to the load. In some cases, such as staged construction and heavier utilities, special consideration may be required.

12.2.4. Downdrag on Deep Foundations (DD)

Reference: LRFD Article 3.11

Deep foundations through unconsolidated soil layers may be subject to downdrag. Downdrag is the phenomenon of a soil moving relative to a deep-foundation element in the same direction as the load applied to the element, typically due to consolidation of soft soils underneath embankments. Drag load, also referred to as downdrag load, is the load developed along the vertical sides of the foundation element due to downdrag.

Calculate this additional load as a skin-friction effect. If possible, detail the deep foundation to mitigate the effects of downdrag; otherwise, it is necessary to design considering downdrag. Chapter 17 discusses mitigation methods.

12.2.5. Differential Settlement (SE)

Differential settlement between adjacent substructure units or transversely across a single substructure unit induces stresses in continuous structures and deflections in simple structures. Although most bridges can easily resist these stresses and deflections, consider the potential effects of differential settlement where applicable.

12.3. Transient Loads

12.3.1. General

The *LRFD Specifications* recognize 19 transient loads, which integrate static water pressure, stream pressure, buoyancy, and wave action as water load, WA. The *LRFD Specifications* elevate creep, settlement, shrinkage, and temperature (CR, SE, SH, TU, and TG) in importance to "loads," being superimposed deformations which, if restrained, will result in force effects. For example, restrained strains due to increasing uniform temperature induce compression forces.

12.3.2. Vehicular Live Load (LL)

General

Reference: LRFD Articles 3.6.1.1, 3.6.1.2, and 3.6.1.3

For short and medium span bridges, which predominate in Alaska, vehicular live load is the most significant component of load. Live load becomes less significant for long-span bridges. Long-span bridges are defined as those governed by the Strength IV load combination where the dead load is seven times or more greater than the live load.

The Nature of the Notional Load

The HL-93 live-load model is a notional load in that it is not a true representation of actual truck weights. Instead, the force effects (i.e., moments, shears) due to the superposition of vehicular and lane load within a single design lane are a true representation of the force effects due to actual trucks.

The components of the HL-93 notional load are:

- a vehicle, either the design truck (similar to the former HS20 truck), or a 50-kip design tandem; and
- a 0.64 k/ft uniformly distributed lane load, similar to the lane load of the *Standard Specifications*, but without any of the previous associated concentrated loads.

A dynamic load allowance (IM) of 0.33 is applicable only to the design truck and the design tandem, but not to the uniformly distributed lane load.

The force effects of the design truck alone are less than that of current legal highway loads. Thus, a heavier vehicle is appropriate for design. As specified for the HL-93 live-load model, the concept of superimposing the design vehicle force effects and the design lane force effects was developed to yield moments and shears representative of real trucks on the highways.

Multiple Presence Factors

The multiple presence factor of 1.0 for two loaded lanes, as given in LRFD Table 3.6.1.1.2-1, is the result of the *LRFD Specifications*' calibration for the notional load, which has been normalized relative to the occurrence of two side-by-side, fully correlated, or identical, vehicles. Use the multiple presence factor of 1.2 for one loaded lane where a single design tandem or single design truck governs (e.g., overhangs, decks) or for single-lane bridges. Do not apply the multiple-presence factors to fatigue loads.

Load Applications

Reference: LRFD Article 3.6.1.3.1

General. Neglect axles that do not contribute to the extreme force effect under consideration (e.g., continuous girders).

Two Design Trucks in a Single Lane for Negative Moment and Interior Reactions

Reference: LRFD Article 3.6.1.3.1

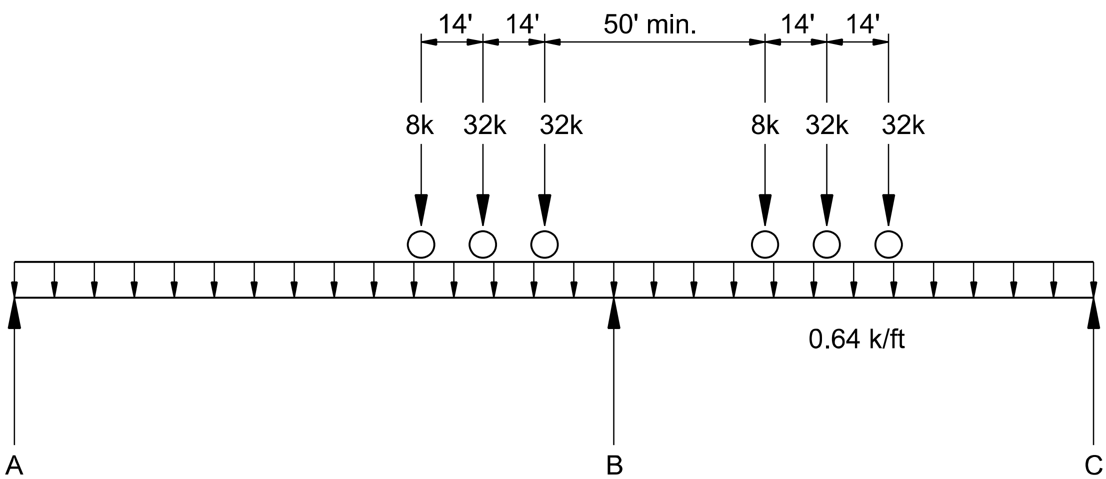
The combination of the lane load and a single vehicle (either a design truck or a design tandem) does not always adequately represent the real-life loading of two heavy vehicles closely following one another, interspersed with other lighter traffic. Thus, the *LRFD Specifications* specify a special load case to calculate these force effects. Two design trucks, with a fixed rear axle spacing of 14 feet and a clear distance not less than 50 feet between them, superimposed upon the lane load, all within a single design lane and adjusted by a factor of 0.90 approximates a statistically valid representation of negative moment and interior reactions due to closely spaced heavy trucks. The *LRFD Specifications* specify this sequence of highway loading for negative moment and reactions at interior piers due to the shape of the influence lines for such force effects. The *LRFD Specifications* do not extend this sequence to other structures or portions of structures because it is not expected to govern for other influence-line shapes. Figure 12-1 illustrates this loading.

In positioning the two trucks to calculate negative moment or the interior reaction over an internal support of a continuous girder, spans should be at least 90 feet in length to be able to position a truck in each span's governing position (over the peak of the influence line). If the spans are larger than 90 feet in length, the trucks remain in the governing positions but, if they are smaller than 90 feet, the bridge engineer can attain the maximum force effect by trial-and-error with either one or both trucks in off-positions (i.e., non-governing positions for each individual span away from the peak of the influence line). When using software, the clear distance between the design trucks will likely need to be varied to determine the maximum force effect. See Figure 12-2.

Application of Horizontal Superstructure Forces to the Substructure. The transfer of horizontal superstructure forces to the substructure depends on the type of superstructure to substructure connection. Assume centrifugal force (CE), braking force (BR), and wind on live load (WL) act horizontally at a distance of 6 feet above the roadway. Connections can be fixed, pinned, or free for both moment and shear.

If the horizontal superstructure force is applied to the substructure through a pinned connection, there is no moment transfer. Apply the superstructure force to the substructure at the connection.

For a fixed or moment connection, apply the superstructure horizontal force with an additional moment to the substructure as shown in Figure 12-3. The additional moment is equal to the horizontal force times the distance between the force's line of action and the point of application.



Note: *Under special loading, use 90% of above.*

Figure 12-1

Special Loading for Negative Moment and Interior Reactions of Continuous Spans

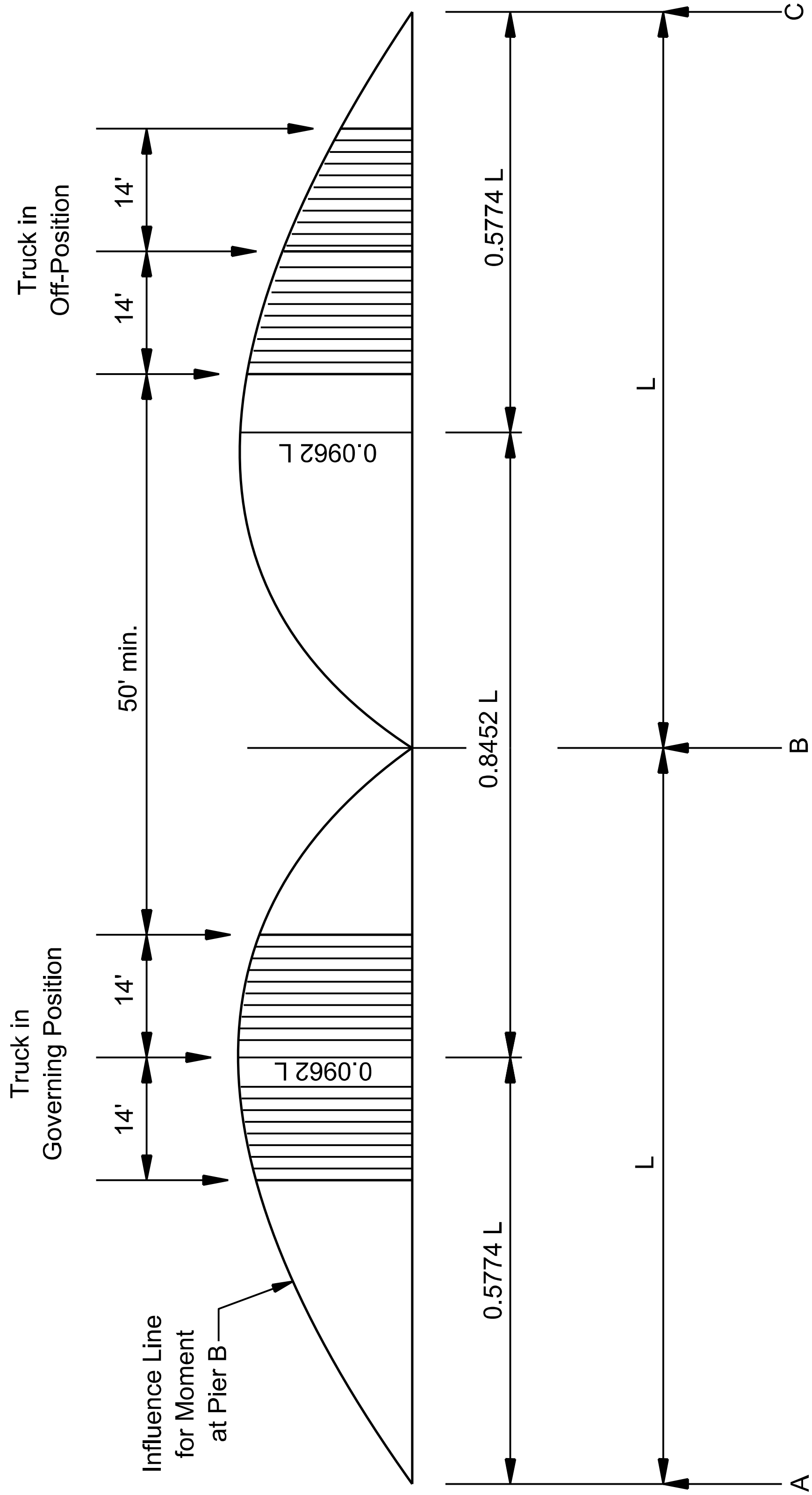


Figure 12-2
Application of Design Vehicular Live Load – LRFD Article 3.6.1.3

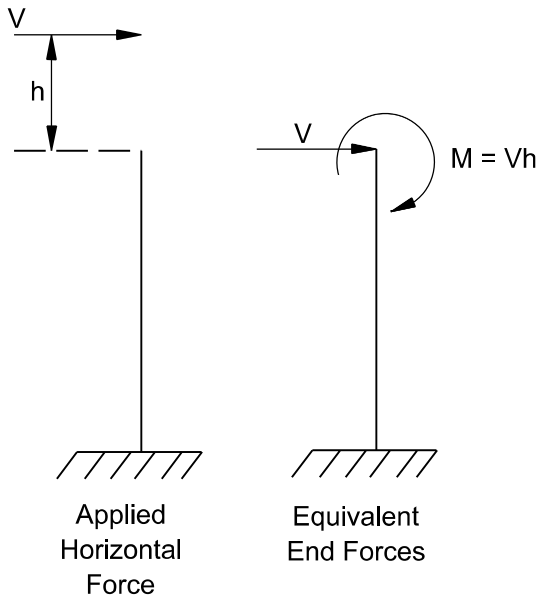


Figure 12-3

Transfer of Horizontal Superstructure Force to Substructure Through Moment Connection

Wheel Load for Deck Design

Reference: LRFD Article 3.6.1.3.3

Design bridge decks to carry axles consisting of two 16-kip wheels with dynamic allowance, alone or in combination with the lane load as appropriate. The design tandem need not be used for the design of decks.

Localized Vehicles

Investigate localized heavy vehicles such as oil field hauling equipment (B-train or oil-field equipment). If localized heavy vehicles are present, consider a site-specific live-load model with the approval of the Chief Bridge Engineer.

Fatigue Loads

Reference: LRFD Articles 3.6.1.4.1, 3.6.1.4.2

The *LRFD Specifications* define the fatigue load for a particular bridge component by specifying both a magnitude and a frequency. The Fatigue I load combination is associated with infinite life, but the Fatigue II load combination is associated with the number of cycles for a 75-year life.

Distribution of Live Load to Piers

Reference: LRFD Article 3.6.1.3.1

To promote uniformity of distribution of live load to piers and other substructure components, use the following procedure unless a more exact distribution of loads is used:

1. **Live-Load Distribution Factor**. Determine the live-load distribution factor for each girder assuming that the deck is acting as a simple beam between interior girders and as a cantilever spanning from the first interior girder over the exterior girder (Lever Rule).
2. **Live Load on Design Lanes**. Place design lanes on the bridge to produce the maximum force effect for the component under investigation. Place the HL-93 live load within its individual design lane to likewise produce the maximum effect. Consider one, two, three, or more design lanes in conjunction with the multiple presence factors of LRFD Table 3.6.1.1.2-1, as can be accommodated on the roadway width.
3. **Reaction on Piers**. For continuous girders or multiple simple span girders, use 90 percent of two closely spaced (i.e. 50 feet) design trucks superimposed over the lane load, with a

distribution factor derived as discussed above in a line-girder analysis to determine the reaction on piers. This is as specified in LRFD Article 3.6.1.3 for negative moment in continuous girders and interior reactions and discussed in Section 12.3.2.4.2.

Sidewalk Loading

Reference: LRFD Article 3.6.1.6

Where sidewalks are present on the bridge, design for the dead load and pedestrian live load on the sidewalk; however, also design the full width of the bridge, including sidewalks, for the traffic live load assuming that traffic can mount the sidewalk. Do not apply pedestrian and traffic loads concurrently. Design for vehicular loads any sidewalks separated from traffic lanes by barrier rail to account for maintenance vehicles and potential future widening.

12.3.3. Friction Forces (FR)

Reference: LRFD Article 3.13

Adjust the frictional forces from sliding bearings to account for unintended additional friction forces due to the future degradation of the coefficient of friction of the sliding surfaces. Consider the horizontal force due to friction conservatively. Include friction forces where design loads would increase, but neglect friction forces where design loads would decrease.

12.3.4. Thermal Loads

Reference: LRFD Article 3.12.2

Use a modified Procedure A of LRFD Article 3.12.2.1 to determine the appropriate design thermal movement range. For Alaska-specific ranges of temperatures and procedures, see Chapter 19 on the design of joints and bearings.

12.3.5. Earthquake Effects (EQ)

Reference: *Guide Specifications for LRFD Seismic Bridge Design*

Use the AASHTO *Guide Specifications for LRFD Seismic Bridge Design* to design bridges in Alaska. Other chapters in this *Manual* present DOT&PF's seismic detailing practices.

12.3.6. Live-Load Surcharge (LS)

Reference: LRFD Article 3.11.6.4

Where approach slabs are provided at bridge ends, consider the reactions on the abutment and wingwall due to the axle loads on the approach slabs plus one-half of the live-load surcharges specified in LRFD Article 3.11.6.4. This applies to walls parallel to or perpendicular to the roadway centerline.

Retaining walls that retain soil supporting a roadway must be able to resist the lateral pressure due to the live-load surcharge. See Chapter 21 for retaining walls.

12.3.7. Vessel/Collision (CV)

Reference: *Guide Specifications and Commentary for Vessel Collision Design of Highway Bridges*, 2nd Edition

Vessel collision is a site-specific consideration that the bridge engineer will consider on a case-by-case basis in active boating channels.

12.3.8. Ice Loads

Reference: LRFD Article 3.9

Apply ice loads as specified in LRFD Article 3.9, but be aware of special situations where historical ice loads have occurred.

Consider ice loads in the conceptual design of the bridge. For example, where historical ice loads have caused problems, consider whether to place a pier in the water.

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