2. AASHTO LRFD Highway Bridge Design Philosophy

2.1. LRFD Method Characteristics

A general statement for assuring safety in engineering design is that the resistance of the components provided exceed the demands effect on them by applied loads, that is:

$$\text{Resistance } (R) \geq \text{Applied Loads } (Q)$$

To account for the variability of both sides of the equation, the resistance side is multiplied by a statistically based resistance factor (ϕ), [$\phi \leq 1$], and the applied load side is multiplied by a statistically based load factor (γ), [$\gamma \geq 1$].

Because of the load effect at a particular limit state involves a combination of different load types (Q_i) that have different degrees of predictability, the load effect is represented by a summation of ($\gamma_i Q_i$) values. If nominal resistance is given by (R_n), the safety criterion is:

$$\phi R_n \geq \sum \gamma_i Q_i$$

Since the above equation involves both load factors and resistance factors. The design method is called Load Resistance Factor Design (LRFD).

The resistance factor (ϕ), for any limit state must account for the uncertainties in:

- Material properties.
- Strength predicting equations.
- Workmanship.
- Quality control.
- Failure consequence.

Also, the load factor (γ_i), for any load type must consider the uncertainties in:

- Loads magnitude.
- Loads arrangement (positions).
- Possible loads combinations.

2.1.1. Advantages of LRFD Method

- Account for variability in both resistance and load.
- Achieves uniform levels of safety for different limit states and bridge types without involving a probability or statistical analysis.
- Provides a rational and consistent method of design.
- Provides consistency with other design specifications (ACI, AISC, …) that are familiar to engineers and new graduates.

2.1.2. Disadvantages of LRFD Method

- Requires a change in design philosophy (from previous AASHTO methods).
- Requires an understanding of the basic concepts of probability and statistics.
- Requires availability of sufficient statistical data and probabilistic design algorithms to adjust in resistance factors.

The basic LRFD design expression in AASHTO bridge specifications that must be satisfied for all limit states, both global and local, shall be taken as:

$R_r \geq Q$

$\phi R_n \geq \sum \eta_i \gamma_i Q_i$

The additional parameter (η_i) is known as load modifier which is incorporated to consider ductility (η_D), redundancy (η_R) and operational importance (η_I) of the bridge. It is given for loads for which maximum and minimum values of (γ_i) are approximated by:

$\eta_i = \eta_D \eta_R \eta_I \geq 0.95$ [for maximum value of load]

$\eta_i = 1/\eta_D \eta_R \eta_I \leq 1.0$ [for minimum value of load]

For ductility, the bridge structural system shall be proportioned and detailed to ensure the development of significant and visible inelastic deformations at the strength and extreme event limit states before failure. The value of (η_D) for various limit states is specified as:

- For the strength limit state:
  - $\eta_D \geq 1.05$ [nonductile components and connections]
    $= 1.0$ [conventional ductile components and connections]
    ≥ 0.95 [additional ductility-enhancing components and connections]
- For all other limit states:
  - $\eta_D = 1.0$

For redundancy, the main elements and components whose failure is expected to cause bridge collapse shall be designated as failure-critical and the associated structural system as nonredundant. Whereas those elements and components whose failure is not expected to cause bridge collapse shall be designated as nonfailure-critical and the associated structural system as redundant. The value of (η_R) for various limit states is specified as:

- For the strength limit state:
  - $\eta_R \geq 1.05$ [nonredundant members]
    $= 1.0$ [conventional levels of redundancy]
    ≥ 0.95 [exceptional levels of redundancy]
- For all other limit states:
  - $\eta_R = 1.0$

The operational importance is applied to the strength and extreme event limit states only. The owner may declare a bridge or any structural component and connection thereof to be of operational importance. The value of (η_I) for various limit states is specified as:

- For the strength limit state:
  - $\eta I \geq 1.05$ [important bridges]
    $= 1.0$ [typical bridges]
    ≥ 0.95 [relatively less important bridges]
- For all other limit states:
  - $\eta_R = 1.0$

2.2. Limit States Concept

A limit state is a condition beyond which a bridge system or bridge component ceases to fulfill the function for which it is designed. There are four types of limit states to accomplish the overall calculations for analysis and design the bridge adequacy and functionality.

2.2.1. Strength Limit States

Five load combinations are intended to ensure that a bridge is providing both local and global strength and stability to resist the expected load combinations during its design life.

- **Strength I**: relating to the normal vehicular use of the bridge without wind. [the basic]
- **Strength II**: relating to the use of the bridge by owner-specified special design vehicles, evaluation permit vehicles, or both without wind.
- **Strength III**: relating to the bridge exposed to wind velocity exceeding $90\ \mathrm{km/hr}$.
- **Strength IV**: relating to very high dead load to live load force effect ratios.
- **Strength V**: relating to normal vehicular use of the bridge with wind velocity of $90\ \mathrm{km/hr}$.

2.2.2. Extreme Event Limit States

Two load combinations are intended to ensure structural survival of bridge during a major earthquake or a flood or when collided by a vehicle, vessel or ice flow.

- **Extreme Event I**: including earthquake.
- **Extreme Event II**: relating to ice load, collision by vessels and vehicles.

2.2.3. Service Limit States

Four load combinations relating to stress, deformation, and cracking under regular operating conditions to last 75 years.

- **Service I**: relating to the normal operational use of the bridge with a $90\ \mathrm{km/hr}$. wind and all loads taken at their nominal values. Also, used for live load deflection control, crack width and investigation of slope stability.
- **Service II**: intended to control yielding of steel structures and slip of slip-critical connections due to vehicular live load.
- **Service III**: for longitudinal analysis of tension in prestressed concrete superstructures with the objective of crack control and principal tension in segmental concrete girders webs.
- **Service IV**: relating only to tension in prestressed concrete columns with the objective of crack control.

2.2.4. Fatigue and Fracture Limit States

Two load combinations are intended to limit crack growth under repetitive loads (loading cycles) to prevent fracture during the design life of the bridge.

- **Fatigue I**: relating to infinite load-induced fatigue life.
- **Fatigue II**: relating to finite load-induced fatigue life.

2.3. Loads and Load Designation

There is a wide range of loads and forces that can act on bridge components as explained above. The designation of these loads can be determined depending on the bridge type, location, and function. Generally, the design loads for bridges are classified into two main groups; they are permanent and transient loads as explained below:

2.3.1. Permanent Loads (Time Invariant)

- CR: force effects due to creep.
- DD: downdrag force.
- DC: dead load of structural components and nonstructural attachments.
- DW: dead load of wearing surfaces and utilities.
- EH: horizontal earth pressure load.
- EL: miscellaneous locked-in force effects resulting from the construction process including jacking apart of cantilevers in segmental construction.
- ES: earth surcharge load.
- EV: vertical pressure from dead load of earth fill.
- PS: secondary forces from post-tensioning for strength limit states; total prestress forces for service limit states.
- SH: force effects due to shrinkage.

2.3.2. Transient Loads (Time Variant)

- BL: blast loading.
- BR: vehicular braking force.
- CE: vehicular centrifugal force.
- CT: vehicular collision force.
- CV: vessel collision force.
- EQ: earthquake load.
- FR: friction load.
- IC: ice load.
- IM: vehicular dynamic load allowance.
- LL: vehicular live load.
- LS: live load surcharge.
- PL: pedestrian live load.
- SE: force effects due to settlement.
- TG: force effect due to temperature gradient.
- TU: force effect due to uniform temperature.
- WA: water load and stream pressure.
- WL: wind on live load.
- WS: wind load on structure.