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# Structural Design of Concrete Bridges

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# 1. AASHTO LRFD Bridge Design Philosophy

## 1.1. 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 multiplying by a statistically based resistance factor $(\phi)$, $[\phi \leq 1]$, and the applied load side is multiplying by a statistically based load factor $(\gamma)$, $[\gamma \geq 1]$. Because 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 $(\phi)$, for any limit state must account for the uncertainties in:

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

Also, the load factor $(\gamma_i)$, for any load type must consider the uncertainties in:

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

### 1.1.1. Advantages of LRFD Method

- Account for variability in both resistance and load.
- Achieves fairly 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.

### 1.1.2. 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 make adjustments 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 $(\eta_i)$ is known as load modifier which is incorporated to consider ductility $(\eta_D)$, redundancy $(\eta_R)$ and operational importance $(\eta_I)$ of the bridge. It is given for loads for which maximum and minimum values of $(\gamma_i)$ 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 $(\eta_D)$ for various limit states is specified as:

- For the strength limit state:
  - $\eta_D \geq 1.05$ [nonductile components and connections]
    $= 1.00$ [conventional ductile components and connections]
    $\geq 0.95$ [additional ductility-enhancing components and connections]
- For all other limit states:
  - $\eta_D = 1.00$

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 $(\eta_R)$ for various limit states is specified as:

- For the strength limit state:
  - $\eta_R \geq 1.05$ [nonredundant members]
    $= 1.00$ [conventional levels of redundancy]
    $\geq 0.95$ [exceptional levels of redundancy]
- For all other limit states:
  - $\eta_R = 1.00$

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 $(\eta_I)$ for various limit states is specified as:

- For the strength limit state:
  - $\eta_I \geq 1.05$ [important bridges]
    $= 1.00$ [typical bridges]
    $\geq 0.95$ [relatively less important bridges]
- For all other limit states:
  - $\eta_I = 1.00$

## 1.2. 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.

### 1.2.1. 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 55 mph.
- **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 55 mph.

### 1.2.2. 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.

### 1.2.3. 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 55 mph. 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 to principal tension in segmental concrete girders webs.
- **Service IV**: relating only to tension in prestressed concrete columns with the objective of crack control.

### 1.2.4. 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.