AASHTO LRFD Bridge Design Specifications: Service IV Load Combination

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Our *ASPIRE*® team recently received a question about when and why we use the provision for prestressed (pretensioned and post-tensioned concrete) substructure solutions with the load combination for the Service IV limit state, which is one of many limit states in the American Association of State Highway and Transportation Officials' *AASHTO LRFD Bridge Design Specifications*.[1] This article aims to shed light on that topic.

Before we address the Service IV load combination specifically, let us first consider the historical development of bridge design specifications. From the issuance of the first bridge design specifications in the late 1920s until early 1970s, bridges were designed by using allowable stress design (ASD) principles. In a nutshell, ASD is based on the premise that stresses created by loads acting on bridges and their components create "working" or allowable stress conditions that must be kept below a certain fraction of actual material strength.

After nearly half a century of successful use, ASD was set aside, and a new direction was taken based on the more rigorous notion of the factor of safety against failure of the section. This was intended to give a more uniform factor of safety against failure, which was not possible with ASD.

For load factor design (LFD), the strength (resistance) of the section was compared to service loads that were individually increased by load factors that were greater than 1.0. Prior to the comparison of strength to demand of the applied loading, the resistance was reduced by a resistance factor that was typically less than 1.0. The magnitudes of the load and resistance factors were based on judgment, considering uncertainty and variability of the loads and section properties.

The transition to load and resistance factor design (LRFD) for concrete simply involved the formal calibration of the load and resistance factors used in LFD design by using statistical methods and field data on loads, material properties, and other aspects. Subsequently, variability in material resistances, the accuracy with which structural capacities can be estimated, and the consequences of different modes of failure were all brought into the LRFD design process.

The first edition of the AASHTO LRFD specifications was published in 1994. Since 1994, the AASHTO LRFD specifications have been revised or updated as our knowledge about the performance of concrete bridges has evolved. Our decisions while developing new techniques, revising older methods, and calibrating load and resistance factors have been informed by data generated in new experimental programs, the advent of increased computing power, the associated development of advanced analysis techniques, and the field performance of concrete bridges.

In the eighth edition of the AASHTO LRFD specifications, which was published in 2017, loads and load combinations are covered in Section 3.[1] As stated in that section, we have five strength limit states, two extreme event limit states, and four service limit states, in addition to the two fatigue and fracture limit states. The Service IV limit state relates to controlling tension in prestressed concrete columns, with the ultimate goal of preventing or minimizing the chances of cracking in these substructure elements to improve durability and maintain a higher flexural stiffness.

Load combinations and load factors from Table 3.4.1-1 in the AASHTO LRFD specifications. Figure: *AASHTO LRFD Bridge Design Specifications*, 8th edition.

Load Combination Limit State	*DC DD DW EH EV ES EL PS CR SH*	*LL IM CE BR PL LS*	*WA*	*WS*	*WL*	*FR*	*TU*	*TG*	*SE*	Use One of These at a Time *EQ*	*BL*	*IC*	*CT*	*CV*
Strength I (unless noted)	γ_P	1.75	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength II	γ_P	1.35	1.00	—	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength III	γ_P	—	1.00	1.00	—	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Strength IV	γ_P	—	1.00	—	—	1.00	0.50/1.20	—	—	—	—	—	—	—
Strength V	γ_P	1.35	1.00	1.00	1.00	1.00	0.50/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Extreme Event I	1.00	γ_{EQ}	1.00	—	—	1.00	—	—	—	1.00	—	—	—	—
Extreme Event II	1.00	0.50	1.00	—	—	1.00	—	—	—	—	1.00	1.00	1.00	1.00
Service I	1.00	1.00	1.00	1.00	1.00	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service II	1.00	1.30	1.00	—	—	1.00	1.00/1.20	—	—	—	—	—	—	—
Service III	1.00	γ_{LL}	1.00	—	—	1.00	1.00/1.20	γ_{TG}	γ_{SE}	—	—	—	—	—
Service IV	1.00	—	1.00	1.00	—	1.00	1.00/1.20	—	1.00	—	—	—	—	—
Fatigue I—*LL, IM & CE* only	—	1.75	—	—	—	—	—	—	—	—	—	—	—	—
Fatigue II—*LL, IM & CE* only	—	0.80	—	—	—	—	—	—	—	—	—	—	—	—

The use of segmentally constructed columns and precast, prestressed concrete columns is currently proliferating as project stakeholders aim to accelerate bridge construction and leverage the greater quality control associated with plant-fabricated concrete elements. Also, post-tensioned cantilever and straddle caps are growing in use as we renew the interstate system. These substructure elements should be designed for many load combinations, including the Service IV load combination. In some cases, the load combination of Service IV may control the design of these substructure elements. The commentary for Article 3.4.1 of the AASHTO LRFD specifications explains the evolution of the Service IV load combinations.

To better understand the historical evolution of the Service IV load combinations, we must appreciate the fact that previous editions of the AASHTO LRFD specifications were based on fastest-mile wind speed. In other words, the wind effects were averaged over different lengths of time over a distance. This approach has been revised and modernized over the years. The current AASHTO LRFD specifications are based on 3-second gust wind speed, which means that the wind speed is averaged over 3 seconds.

The use of a large number of loads and load combinations is commonly facilitated by design software. Using computers for the analysis and design unquestionably gives us a chance to improve the precision and levels of reliability in our structural designs to a degree we could not have dreamed of during the major infrastructure expansion in the United States after the conclusion of World War II. Establishing uniform levels of safety has many design and cost benefits and reduces environmental impact by removing unnecessary conservatism (that is, overdesign) where appropriate. With these important goals stated, we must remain alert in our designs to ensure that all important or controlling load applications are considered. Limiting tensile stresses in prestressed concrete (both cast-in-place and precast) substructure elements (piles, caps, footings, and columns that are pretensioned or post-tensioned) while in a fabrication plant and during transportation, erection, construction, and service is an important goal of design as we aspire to see our concrete bridges serve our communities for at least 100 years.

Service IV load combination was used to design the precast concrete segmental substructures for the U.S. Route 183 elevated viaduct in Austin, Tex. Photo: Dr. Oguzhan Bayrak.

Reference

1. American Association of State Highway and Transportation Officials (AASHTO). 2017. *AASHTO LRFD Bridge Design Specifications*, 8th ed. Washington, DC: AASHTO.