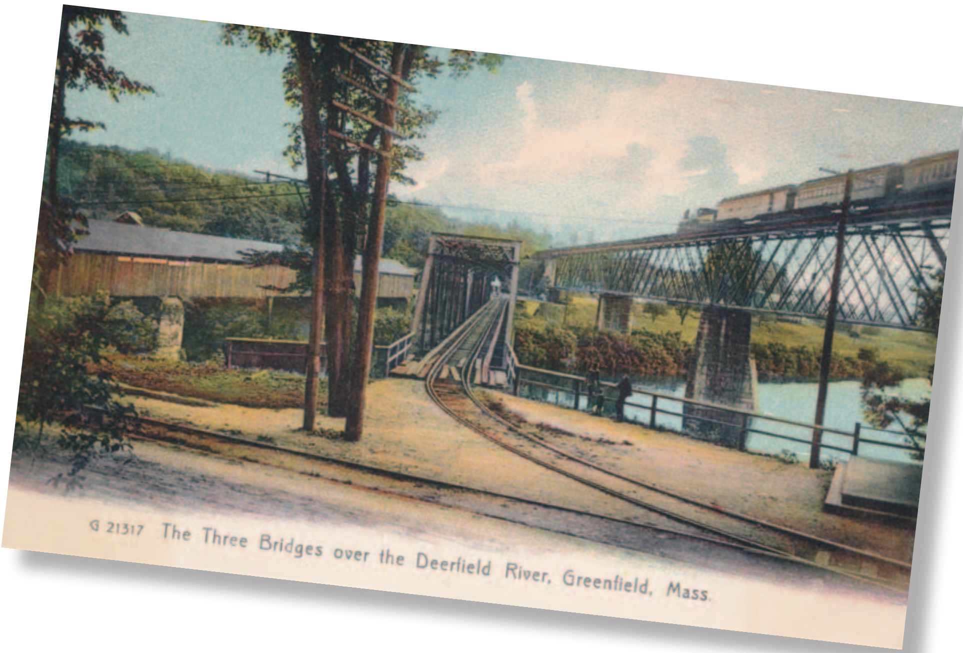
Everything you never knew you wanted to know about ASD and LRFD design

BY MIRIAM PASCHETTO



Different bridges crossing the same river are much like ASD and LRFD, which provide different routes to safe structural designs.

FOR ANYONE WHO has encountered the engineering design acronyms ASD and LRFD and wondered what the heck they are, this article will (I hope) enlighten you. I'm going to start off with a broad overview of the differences between the two approaches and then I'll go into greater depth for those readers who are interested in knowing more.

In structural engineering, the demands placed on a structure or structural member must be less than what the engineer designs the structure to support. Pretty simple. You don't want the structure to be overstressed by the loads put on it and risk failure during normal service. In fact, you want to have extra capacity that provides a margin of safety.

There is general consensus in the structural engineering community regarding just how large this safety margin should be. The design philosophies Allowable Strength Design (ASD) and Load and Resistance Factor Design (LRFD) are the two recognized methods engineers use to ensure they design adequately safe structures.

Before going further, here's a short glossary for easy reference:

Allowable Strength: ASD nominal strength divided by the appropriate safety factor

ASD – Allowable Strength Design (formerly Allowable Stress Design)

Dead Load: Self-weight of a structure/member along with loads from things always in place such as headblocks in a theatre's fly grid

Design strength: LRFD nominal strength multiplied by the appropriate resistance factor

LRFD – Load and Resistance Factor Design

Live load – Most often loads from people but more generally, loads that are less predictable than dead loads

Nominal strength – Unfactored capacity of the structure or structural member being designed or analyzed

Plastic modulus, Z – Geometric property of a member associated with bending at the point where the entire cross section is yielding

plf – Pounds per lineal foot

psi – Pounds per square inch

Required strength – Structural capacity needed to meet or exceed the demands put on the structure by the loads, either ASD or LRFD

Section modulus, S – Geometric property of a member associated with bending just at the point where the outer surface material starts to yield.

Yield strength – The capacity at or just below the point where the structure experiences permanent deformation (that is, it does not return to its original shape when loads are removed.)

Omega – ASD safety factor for bending moment

Phi – LRFD resistance factor

In the broadest strokes, the engineer uses unfactored loads and factored yield strength in Allowable Strength Design (ASD) while in Load Resistance Factor Design (LRFD) both loads and strength are factored and the strength is ultimate rather than yield.

ASD provides the desired factor of safety by limiting how much of the structure's capacity can be utilized under applied service loads. This is the "allowable" strength of ASD and it is in the range of 60% of the structure's yield strength. The effects on the structure from the applied unfactored or service loads are calculated and the required strength to resist these effects is compared to the allowable strength.

Thus, the necessary safety margin is maintained by designing structures to have yield strengths large enough so that the resulting allowable strength is larger than or equal to the strength required to support the service loads. If the ASD loads demand a capacity that is greater than the allowable strength, then the structure needs another round of design to beef it up. If not, the structure is adequate as is.

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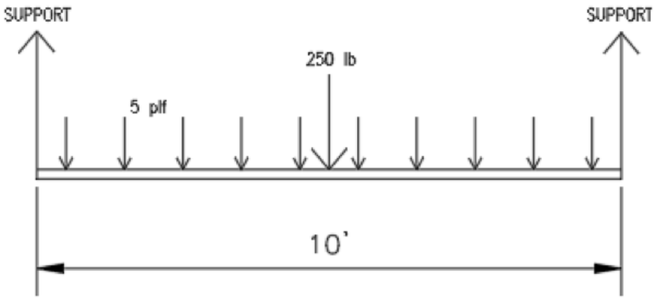
LRFD, Load and Resistance Factor Design, on the other hand, achieves a safe structural design by a slightly different route. With LRFD, both the loads and the nominal strength are factored to determine the design parameters. The anticipated demands on the structure are increased by applying factors greater than 1.0 to the loads. The structure's design strength is calculated by reducing its LRFD nominal or ultimate strength by a specified percentage. Note that an LRFD design strength is never referred to as "allowable" to prevent confusion with ASD.

To review, in ASD the loads are used "as is" and a structure's design strength is equal to its elastic failure strength, reduced by factors. In LRFD the loads are increased and at the same time the structure's ultimate strength at failure is slightly reduced to determine the design strength. Increased loads are used for design in LRFD and therefore the design strength can be taken closer to the material's failure point.

I am glossing over the elastic versus ultimate strengths a little bit here. It is sufficient to know that in many cases LRFD allows the designer to take advantage of more of the structure's capacity than is permitted in ASD. Thus, even though it might look like all the different factors in the two methods amount to the same thing in the end, LRFD will often result in a more efficient design. That is, LRFD will sometimes lead to a lighter member being used.

To illustrate with a very simple example of sizing a pipe batten:

- Span = 10' (supported at each end)
- Loads:
  - 5 plf dead load – estimate of pipe batten's self-weight plus scrim's weight
  - 250 lb live load – point load from scenic piece



- ASD
  - Design loads – as shown
  - Required strength, bending moment, M = 687.5'-lb
  - Yield stress, Fy = 35,000 psi
  - Safety factor, Omega = 1.67
  - Allowable stress, Fb = Fy/Omega = 20,958 psi
  - Minimum section modulus, S, required = M/Fb = 0.394 in^3
  - 1-½ STD pipe has S = 0.309 in^3, less than minimum S required, no good, try larger pipe size
  - 2 STD pipe has S = 0.528 in^3, greater than minimum S required, OK
- LRFD
  - Design loads – use 1.2 dead load factor and 1.6 live load factor:
    - 1.2x 5 plf = 6 plf
    - 0.6 x 250 lb = 400 lb
  - Required strength, bending moment, M = 1,075'-lb
  - Yield stress, Fy = 35,000 psi
  - Resistance factor, Phi = 0.9
  - Design stress, Fb = phi_b x Fy = 31,500 psi
  - Minimum plastic section modulus, Z, required = M/Fb = 0.41 in^3
  - 1-½ STD pipe has Z = 0.421 in^3, greater than minimum S required, OK

Especially when designing members to resist bending moment, LRFD will often mean a more efficient design as in this example. With ASD, the necessary pipe size was determined to be a 2" STD. LRFD design gave a pipe size of 1 ½" STD. The designer is permitted to utilize more of a member's inherent strength in LRFD.

Clearly, it is important to know which method is being employed in any design or analysis process. Many people state vigorously that ASD and LRFD should never both be used on the same project. I will address that further on because in reality it sometimes makes sense to do so, as long as steps are taken to keep careful track of what's being done. For now, just grasp that it's important to always know whether any loads and strengths are ASD or LRFD. Let's look at the two ways to get things mixed up: one would lead to a very conservative (much stronger than necessary) structure and the other to a situation where the structure could be described as being on "thin ice."

If an engineer applies LRFD factored loads to a structure but designs to an ASD allowable strength, the structure will have a larger than necessary factor of safety. The effect on the structure of the higher factored loads will be compared to the relatively low allowable strength. This is not dangerous but the structure would be over-designed by roughly 50%, which wastes material and money.

If, however, the engineer applies unfactored ASD loads to the structure and then designs for LRFD strength, the structure will have a grossly inadequate factor of safety. Consider if the engineer designs using the 110 psf ASD combined load from the illustration above and then compares the associated required strength against the LRFD design strength, there would be a small safety margin. Imagine flying a rigging grid that when loaded by show loads is only 10% away from failure. Based on the experience of the engineering community, that's an unacceptably slim margin of error. In the illustration, only 11 psf more load on the structure and it would be at its failure strength.

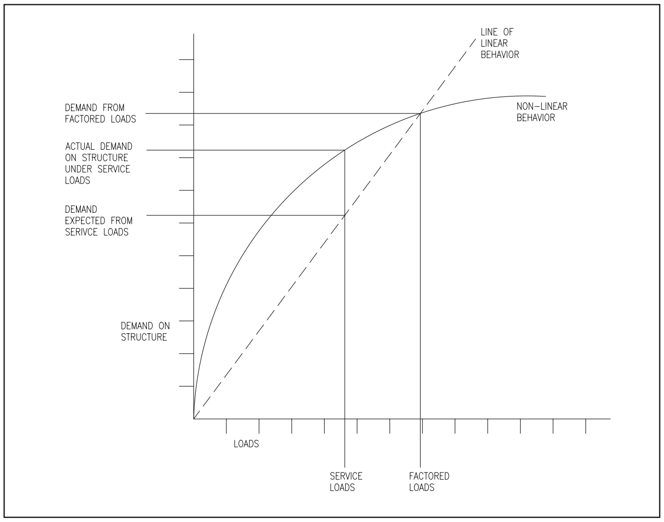
This dangerous mix up of the two methods is why engineers will constantly ask when given a set of loads, or member results, or strengths, "Is this ASD or LRFD?"

But, why use two different design approaches at all? Well, as with many such things, the answer is partly historical. Centuries ago, structural members were sized based on rules of thumb developed through experience. There was no such thing as structural analysis. Then in the 1800s engineers began running experiments and developing theories based on the results. By the early 1900s, elastic behavior (that is, when you load and unload a structure and it always returns to its original shape) was becoming well understood and the ASD method grew out of that knowledge.

As early as the 1930s and 1940s, the research was being done that would eventually lead in the 1970s to the concrete industry's adoption of LRFD for designing reinforced concrete. By the 1990s, the steel industry started to move in the same direction, although the latest *Manual of Steel Construction* still supports ASD. Indeed, many engineers still use ASD for designing steel. It is slightly easier to use than LRFD; an experienced design engineer can frequently determine a member size by doing the necessary ASD calculations in their head. This can be useful in many situations where at the moment the engineer is only trying to determine feasibility with a rough estimate.

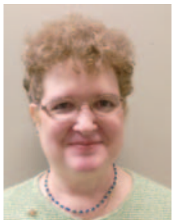
More important is that ASD is necessary when designing a non-linear structure. Something is non-linear when the structure's response does not change at the same rate as the applied loads. For example, if the loads are doubled the stress in the structure does not double. It changes by some other multiple, could be 1.8 or 2.5. There is no easily discernible pattern; the loads could be doubled a second time and the stress will change by another multiple, maybe three. Therefore, the structure needs to be designed for the actual, anticipated, unfactored loads as are used in ASD. An important category of non-linear structures are tensile fabric roofs.

Below is a graph illustrating why LRFD should not be used for non-linear structures. The solid line represents the non-linear behavior of the structure—loads vs demand. If the engineer designed using factored loads, then the demand on the structure under service loads would be much higher than if the structure were linear. As can be seen, the demand on the non-linear structure under service loads is much closer to the demand under the factored loads. There is not as much extra capacity as needed to ensure a safe design. When using LRFD, the desire is for the service load demands to be much lower as is indicated for the linear behavior line.



With ASD, the engineer designs for the actual loads that the structure is expected to see. That way, the demands that will be placed on the structure are correct and the designer can then apply the appropriate factor of safety.

In summary, perhaps it seems that the structural engineering world should simply switch to LRFD for design and analysis. It leads to more efficient structures, saving on materials and cost. But ASD will always have a place—not just for non-linear structures, but also for engineers' "back-of-the-envelope" calculations. ■



Miriam Paschetto is a licensed P.E. in New York State and works as an Associate at Geiger Engineers. For the past 16 years she has provided structural engineering services for entertainment projects around the world, among them the center hung scoreboard support structures for the Sacramento King's new arena; the outdoor sound system supports for SunTrust Park in Atlanta; rigging capacity analysis for Notre Dame's Joyce Center; the outdoor stage for the 150th Cinco de Mayo Celebration in Puebla, Mexico; and numerous Super Bowl halftime shows and outdoor music festivals' stages. Miriam is active in ESTA's Rigging and Event Safety Working Groups and has served on the Temporary Structures and Aluminum Trusses and Towers Task Groups. She is currently participating in the Structures Task Group of the Event Safety Working Group. She is also a member of the American Society of Civil Engineers and the Structural Engineers Association of New York. Miriam has published past articles in *Protocol* and given presentations at NATEAC, the 2015 Event Safety Summit, and the 2011 Structural Engineering Institute's Structures Congress.