Review of Design Code Experiences in Conversion from ASD Methodology to LRFD Methodology

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Introduction


In the AISC-05, two design methodologies are specified—Allowable Strength Design (ASD-05) and Load and Resistance Factor Design (LRFD-05). The ASD-05 design methodology is similar in concept to the Allowable Stress Methodology (ASD-89), where the nominal loads are combined without any load factors. The older methodology (ASD-89) uses stress basis criteria while an ASD-05 use loads; forces and moments. The ASD-89 and ASD-05 methodologies have several major differences that will be discussed later. The ASD-05 and LRFD-05 design methodologies are not identical and not interchangeable. An indiscriminant mix of the LRFD and ASD methods might lead to unpredictable structural system performance since the code calibrations and reliability analyses were based on individual member limit states rather than system limit states.

The newer methodologies, ASD-05 and LRFD-05, include changes that reflect advancements and developments since the 1989 specification was published. The LRFD-05 method is now

being accepted worldwide for member strength evaluation and, in general, is replacing the allowable stress design method.

**API 4F Transition to LRFD Method**

The API 4F committee that oversees and revises the 4F specification is beginning the task of transitioning to the latest edition of the AISC code and likely to the LRFD methodology therein. An initial concern for the committee was to understand the problems that might arise upon conversion from the ASD-89 methodology to the use of the latest edition of the AISC specification. This paper was requested to investigate and document problems previously encountered after other codes were converted to the LRFD methodology.

API 4F task group also requested Stress Engineering Services (SES) to perform a benchmark study of five drilling structures ranging from a guyed workover mast to a deepwater dynamic derrick. The task group’s objective for the work is to transition to the use of the latest edition of AISC while providing structures with reliability equal to or greater than existing structures. SES’s work tasks for this study are:

1. Analyze and compare the structures with the existing AISC ASD-89 specification and the AISC ASD-05.
2. Perform a sensitivity study of the structures using AISC LRFD-05 specification varying the load factors for the design drilling loads.
3. Study the effect of the $\frac{1}{3}$ stress allowable increase.
4. Document the study results.

**Wind and Seismic Stress Allowable**

In the ASD-89, under Section A5.2 is a section that states to “increases the allowable stress $\frac{1}{3}$ above the value otherwise provided when produced by wind and seismic loading, acting alone or in combination with the design dead and live loads, provided the required section computed on this basis is not less than that required for the design dead and live load and impact computed without the $\frac{1}{3}$ stress increase, and further provided that stresses are not otherwise required to be calculated on the basis of reduction factors applied to design loads in combinations.”
This allowable was originally for wind loads in combination with other dead and live loads. The earthquake provision was added later. Engineers from the west coast and building official lobbied to have the provision removed as far back as the mid to late 1970’s.[3]

This allowed stress increase provision was removed in the first supplement to this specification in 2002. The supplement also introduced the load combination in ASCE 7. API 4F still allows the 1/3rd stress allowable increase with their specified load combinations. API RP2A in the working stress design version also still allows the stress allowable increase.

**LRFD Method**

The LRFD methodology traces its origin back to the 1960s in response to structural failures that exposed deficiencies in the structural code, in either strength allowables or loads. The Allowable Stress Design method was observed to result in inconsistent safety factors. The LRFD method was adopted to provide a more consistent safety factor for a design as well as individual issues, so that load or strength aspect issues could be addressed separately. [4]

A major difference between the ASD and LRFD methods is whether load factors are applied to the loads. The ASD methods use unfactored design loads. All safety factors are applied to the material strength and minimum specified yield stress, resulting in allowable loads or stresses. The LRFD method applies load factors to the loads based on the known accuracy or reliability of the load values and a resistance factor to the material strength to account for uncertainties in materials. For instance, in building design, dead loads are well known and have a relatively low uncertainty where live loads can vary significantly. To account for this variability, the load factor is significantly higher for live loads. The LRFD method is designed to provide more consistent safety factors. AISC specifications since 1993 direct the designer to the ASCE 7[5] publication, “Minimum Design Loads for Buildings and Other Structures,” for design loads and design load factors for various loads and load combinations unless are otherwise specified. ASCE 7 specifies load combinations for both ASD and LRFD methodologies.

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The load factors given in ASCE 7 may not be appropriate in some cases for the design of drilling structures. An initial task is to investigate these load factors. For example, another specification, API RP 2A-LRFD (presently withdrawn), provides load factors that differ from those in ASCE 7.

**Conversion to LRFD Methodology**

In general, there are two approaches\(^6\) to developing load and resistance factors for the LRFD methodology:

1. Select a target level of reliability and then estimate LRFD load and resistance factors based on statistical studies
2. Determine the average reliability level of structures that were designed using the existing codes and standards, and use the average reliability level to estimate LRFD load and resistance factors

The second method was used to develop load and resistance factors for the AISC-LRFD specification. The LRFD is calibrated to the AISC 78-ASD specification at a ratio of live load to dead load of 3 to 1. For live load to dead load ratios less than 3, members designed by the LRFD method will be lighter; conversely, for ratios greater than 3, the LRFD method will yield heavier members. An LRFD methodology will result in a more uniform level of safety as the load and load factors are adjusted on a member-by-member basis, whereas the ASD methodology applies a single safety factor to the structure and loads for the structure. Due to this fact, the LRFD method will provide a more uniform level of safety than the ASD method.

**Discussion of AISC 13\(^{th}\) Code**

From 1986 to 2005, AISC maintained two separate specifications, one for the allowable stress method (ASD-80 & ASD-89), and another for LRFD methodology (LRFD-86, LRFD-93, & LRFD-99). Many (if not most) universities discontinued teaching the allowable stress or strength design method (ASDM) in 1986. AISC stated that they would not publish a new ASDM specification after the 1989 version was issued, but many industries continued to use the ASD-89

method exclusively. Due to this resistance to change and the fact that there are significant changes since the ASD-89 specification, AISC published a new specification in 2005 that incorporated the LRFD method along with a new methodology that uses strength rules of the LRFD method, but is based on the same design concept as the ASDM. This new method is the “Allowable Strength Design” method (ASD-05), which uses unfactored loads and performs checks against nominal strength with a safety factor. The basic equations of structural mechanics that underlie the LRFD and ASD-05 methods are the same. In addition, AISC-05 specifically states that second-order (p-delta) effects should be included in the analysis. Stability provisions prior to the 2005 specification mentions that one should consider the stability effects in the design. In AISC-05 specification, it is explicitly stated that the second order effects such as P-Δ, axial, shear, and bending deformations, geometric imperfections, and member stiffness reduction due to residual stress should be considered in the analysis to determine the load effects. In addition, different acceptable analysis methods are provided in the specification. Due to advancements in computers and software, this task is now relatively easy to complete.

**Challenges Developing the Allowable Strength Design Methodology**

The AISC committee encountered challenges while developing the Allowable Strength Methodology (ASD-05). It is necessary that the new Allowable Strength Design (ASD-05) methodology produce strength results that are the same as those from the LRFD methodology. Difference in strength results between ASD-89 and ASD-05 are changes in safety factor between the two methods.\(^7\)\(^8\)

One area where the ASD-89 and ASD-05 methods are different is in the evaluation of members’ minor axis bending capacity. ASD-89 calculates stresses using elastic section modulus and checks the member with a safety factor applied to member material yield strength. ASD-05 uses the member forces and moments and checks the loads against an allowable force and moment. The allowable moment is the product of the plastic section modulus and the material yield strength. The difference in using the plastic section modulus versus the elastic section modulus

\(^7\) Emails and Telephone Discussion with Charlie Carter, AISC Vice President and Chief Structural Engineer, Spring 2012
\(^8\) Modern Steel Design, May 2005, ‘All About Flexure’, by Louis F. Geschwinder
is an increased allowable. The use of the plastic section modulus is consistent in evaluating members in the ASD-05 and LRFD-05.

**Load Factors (ACI)**

ACI 318-56, “Building Code Requirements for Reinforced Concrete,”[9] first introduced the ultimate strength methodology in the 1956 Edition. The ultimate strength methodology is very similar to the present LRFD methodology in concept. Concrete textbooks[10] indicate that the ultimate strength methodology was first introduced in the late 1890s by Thullie and Ritter. Another methodology was also introduced that assumed elastic theories based on a linear variation of concrete stress with distance from the neutral axis. Because of the linear theory simplicity, the “straight line” theory gained acceptance and was adopted in the early codes. Later in the 1930s, concrete testing indicated that measured steel stresses were considerably higher than predicted by elastic theory. Therefore, the industry transitioned the concrete code to include the ultimate strength methodology. ACI 318-56, the earliest code that incorporated the ultimate strength design methodology, provided its own load factors. A later edition, ACI 318-71[11], modified the load factor and reduced its conservatism. Concrete texts[12] published for the 1971 concrete code agreed with the reduced conservatism. Later, the ACI 318-95[13] specification provided an alternate design method that uses ASCE 7 load factors. ASCE 7 provides minimum design load for buildings and other structures and is adopted by U. S. building codes. This document provides loads, load factors, and load combinations for design and analysis. The ASCE 7 load factors currently used were generally developed in 1980 by Ellingwood, Galambos, MacGregor and Cornell.[14] The ACI 318-56 and -71 load factors were conservative for dead and live loads when compared to the ASCE 7 load factors. It should be noted that alternate strength reduction factors used with the ASCE 7 load factors introduced lower strength factors that yield similar designs as previous editions of the ACI code.

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[9] ACI 318-56
[13] ACI 318-95
The original ultimate strength load factors were changed in the 1971 code by reducing the load factors, resulting in lighter designs. Applying the ASCE 7 load factors, which are lower than the 1971 load factors, with the alternate design method in ACI 318-95 was offset by using lower strength factors that resulted in equivalent designs produced by 1971 ACI load factor designs.

**ASCE 7 Load Factors**

As mentioned earlier, ASCE 7 load factors developed in 1980 are still in use today with minor changes. ASCE 7 has itself been revised multiple times with updates and revisions. The wind loads have been changed from the fastest-mile gust to the 3-second gust. In ASCE 7-2010\(^{[15]}\) edition, the wind speeds have been changed from design loads to ultimate loads. This resulted in the load factors for wind loads being changed from 1.6 to 1.0 for LRFD design and 1.0 to 0.6 for ASD design methodology. The resulting product yields the same or similar factored loads as previous ASCE 7 results. The ASCE 7 nominal wind loads for certain locations in the continental United States have been reduced due to increased statistical data that have allowed the factored wind load to be lowered.

**API – RP2A-LRFD**

This API document is presently withdrawn and is being updated. API RP2A-LRFD\(^{[16]}\) provides load factors and load combination different from the load factor and load combinations in ASCE 7. No changes to the load factors are known at this time but a JIP is proposed to further study these load factors.\(^{[17]}\)

**DNV-OS-C101**

Another LRFD document for offshore structures was issued in April 2011, ‘Design of Offshore Steel Structures, General (LRFD Method)’. This document has its own load factors and references AISC LRFD Manual of Steel Construction. The document does not give a specific set of load combinations but give guidance on the development of load combinations.\(^{[18]}\)

\(^{[15]}\) ASCE 7-2010  
^{[16]} API RP 2A-LRFD  
^{[17]} Conversations from Farrel Zwerneman at API Task Group 19  
^{[18]} ‘Offshore Standard DNV-OS-C101 Design of Offshore Steel Structures, General (LRFD Method)’, April 2011
Technical & Research Bulletin 5-5A

The primary guidance used by the jack-up industry is Society of Naval Architects and Marine Engineers (SNAME) Technical and Research Bulletin 5-5A, “Guidelines for Site Specific Assessment of Mobile Jack-Up Units”. The first edition of T&R Bulletin 5-5A was issued in 1994. Evaluation of existing structures using the LRFD method and load factors in T&R Bulletin 5-5A, First Edition indicated some of the previously acceptable designs evaluated using the ASD methodology were unacceptable. Later editions of the document lowered the load factor for environmental loads (wind, wave, and current). This change was lowered with acceptable rationale provided.[19] [20]

Introduction of Performance-Based Design in ASCE 7-10

ASCE 7 now provides alternative performance-based procedures to cover various aspects of a member design that do not fit the standard. ASCE7-10 provides the basic steps designers might pursue to demonstrate that a structure provides appropriate reliability based on analysis and testing. This feature provides the code and code committees the flexibility to adjust portions of the methodology as needed, for example, in reducing or increasing the load factor(s).[21] [22]

Conclusions

LRFD methodologies provide a framework to modify the load factor and resistance factors based on newly available data and research. Literature searches and conversations with other code committee members indicate that there are no major issues regarding transition from the Allowable Stress Methodology to the LRFD Methodology, since the underlying reliability level in the LRFD specification is based on existing designs.

For the design study, API 4F committee provided 6 structures. Load factors will be proposed from this design study. The limited database should be trial tested by API 4F designers.

[19] Email from David Lewis, Lewis Engineering Group
API designers should test their existing designs using the new LRFD methodology and the proposed load factors and load combinations. This trial-test will provide more data to compare the effect of changing from ASD to LRFD methodology and help reduce the need for revisions to the load factors after they are published.

ASCE 7 has changed the loads and load factors with revisions of the standard. Since API 4F for United States land rig specifies wind loads from ASCE 7, users should not use other versions of the standard than specified.