LRFD and the Structural Engineering Curriculum

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The new Load and Resistance Factor Design Specification for Structural Steel Buildings [4] will eventually replace the existing Allowable Stress Design Specification[5] for normal engineering design. The speed with which this takes place depends to a large extent on its inclusion in basic undergraduate curriculum. Past experience with major changes in code concepts, such as the reinforced concrete code change from working stress to ultimate strength, has shown the integration of these new concepts into professional practice is due, in large part, to the influx of new graduates into practice.

This paper looks at the incorporation of LRFD concepts into a structural engineering curriculum. It identifies some of the advantages and disadvantages of both allowable stress design (ASD) and load and resistance factor design (LRFD) and proposes four options for addressing LRFD and its impact on an academic program.

LRFD—WHAT IS IT?

The first question to be asked is, what is LRFD? There has been a great deal of publicity associated with the introduction of this new design approach—and numerous articles in the professional journals include these four letters in their title. LRFD, we now know, is load and resistance factor design, an approach to design for steel building structures based on reliability.

The basic equation used to describe the principles upon which this approach is founded is given by:

$$\Sigma \gamma_i Q_i \leq \phi R_n \tag{1}$$

This equation can be found on the cover of the American Institute of Steel Construction (AISC) flyer advertising their recently completed nationwide educational program, as well as in almost every paper dealing with LRFD. Along with Eq. 1, the bell-shaped curves in Fig. 1 regularly appear in papers addressing the development or application of LRFD. These curves represent the statistical variation of load effect and resistance, and form the foundation for LRFD.

In the opinion of the writer, Eq. 1 provides one of the major stumbling blocks in the acceptance of the method—and the bell-shaped curves of Fig. 1 provide the other. Every technical presentation seems to emphasize these features and the statistical base upon which LRFD has been developed. Practicing engineers tend to look at these with concern, since very few of them will have a solid understanding of statistics. This is unfortunate, since some engineers become turned off to LRFD and thus miss the many advantages and so many more opportunities to put it into practice.

Although no textbooks are yet available for teaching LRFD, there are numerous resources available to support the effort. The results of the research conducted by T. Galambos were first published in 1978[2,7,9] and provide the basic resources for the development of the method. In 1983, the proposed LRFD Specification[6] was published; and in 1986 the new LRFD Specification and Manual of Steel Construction[4] were published. The most important components of the manual for classroom use are the specification and commentary, since they are the closest thing to a text available. Of course, they should be primary reading for any engineer planning to use the LRFD Specification. The LRFD Manual also contains the most up-to-date list of steel section properties available, including

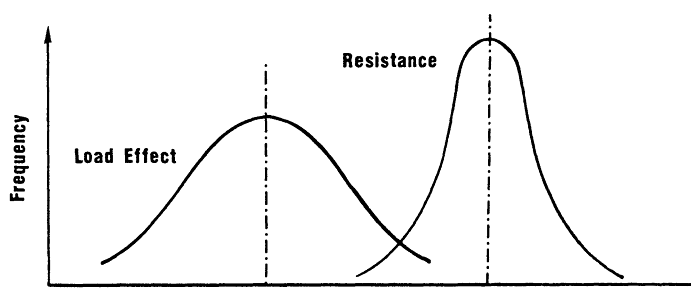

Fig. 1. Probability distribution of load effect and resistance

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shapes up to the W40s and W36 shapes up to 848 lb./ft. In addition, AISC has published a *Guide to LRFD*[3] Specification which should be of help.

OPTIONS

The writer believes the future of LRFD depends on the educators of this country. Educators, through their decisions to teach or not to teach LRFD to future engineers, are now providing the knowledge base for the profession of the future. If students learn LRFD in school, they will want to use it in practice. If the faculty do not teach it, the students will not learn it, and the incentive to learn it after graduation and entry into the field will be diminished significantly. This opinion is not completely accepted by other educators, but is the basis upon which this paper is developed.

So, what options are open to educators? There appear to be four choices, to be addressed individually. First, LRFD may be ignored. It does not appear this is really an option for either the academic community or the profession. At the other extreme is the option to switch completely from ASD to LRFD. This implies a complete replacement of all allowable stress design concepts with LRFD. At least one university has taken that approach with its Spring 1987 classes. This may be the easiest approach when it comes to fitting it in curricula. However, the concern generated with this approach relates to how those students will fit into a profession which has not yet totally embraced the concepts of LRFD.

In between these two extreme options is the option to designate LRFD for a graduate course. This would make it available only to the better students, assuming the better students are the ones in graduate school. Thus, the majority of undergraduates would not have the opportunity to study LRFD extensively. Also, between the extremes is the option to integrate ASD and LRFD into a single course. The problems associated with this approach will be well understood by every faculty member who has tried to fit more material into an already overloaded course.

WHERE ARE WE NOW?

Before each of these options can be fully evaluated, take a look at the current situation in academia. The typical civil engineering program includes an analysis course, a steel design course and a concrete design course and, for structural majors, up to three additional courses from which to choose. Architectural engineering at Penn State has the luxury of being a 5-year undergraduate program. This allows for more flexibility than a typical 4-year program and results in the requirement of eight structures courses for students in the structures option.

Regardless of program designation or number of years, there are additional topics that normally do not get covered. Although these topics may be very worthwhile, there are limits to what can be covered in the available time. Some of these topics would include masonry, wood, dynamic analysis, finite element analysis and now, LRFD. So LRFD is just one additional topic that must be evaluated for incorporation into a program. That evaluation must be based, in large part, on a comparison between LRFD and ASD and the relative merits of each. The profession, too, is asking "What's in LRFD for me?," and "What direction should I take"?

LRFD vs. ASD—
ADVANTAGES AND DISADVANTAGES

First consider some of the advantages of ASD:

1. *Tradition*. We think we know where it came from, we are used to using it and that is the way it has always been done.
2. *Familiarity*. This is perhaps another way to say the same thing. We know allowable stress design, we know what kind of answers we are going to get and we know what those straight line stress diagrams mean. We probably all forgot about the limitations and approximations inherent in ASD that we were told about as students.
3. *Simplicity*. Some people say ASD is simple. Those who have worked on the development of design specifications might not agree with that, but it has been suggested by others as an advantage.
4. *Experience*. A big advantage for ASD is that experience shows it works. We know we have satisfactory behavior since we do not have a large number of structural failures of buildings due to design specification.
5. *Convenience*. Change is always inconvenient. Even change which results in a more economical design approach will be inconvenient, and thus resisted.

There are, of course, disadvantages to the continued use of ASD:

1. *Reliability*. Reliability is not uniform over the many different conditions of design. Thus, we never really know what the factor of safety is for the many individual components or for a system as a whole.
2. *Arbitrary*. The basis of allowable stress design is hidden within arbitrary allowable stresses and factors of safety. Tests are carried out to determine the strength of an element, that strength is divided by some factor and an allowable stress is defined. In effect it is based on LRFD principles obscured by our manipulations.
3. *Format*. The format of ASD is not consistent with the one used for reinforced concrete, nor is it consistent with those of the international community.

There may be other advantages or disadvantages to ASD, but this should be sufficient to set the stage for looking at LRFD in a similar way.

Since LRFD is the new approach, it is normally presented with the largest list of advantages. It will be instructive to look at these again:

1. *Reliability*. Consistency is the key to reliability in LRFD. For a wide range of design situations, a relatively uniform level of reliability may be achieved.
2. *Adjustable safety*. Reliability may be adjusted to reflect the consequences of failure for unique designs where the designer wishes to control safety in a manner different than normal.
3. *Behavior*. The entire structure of LRFD requires the designer have a better understanding of structural behavior. From an educational standpoint, this is perhaps its most significant advantage.
4. *Simplified structures*. As a discipline, structural engineering is simplified by encouraging a uniform approach across all materials.
5. *Judgement*. LRFD provides a tool for exercising judgement in those non-typical situations where the designer is not quite sure of all of the details.
6. *Update tool*. The statistical base of LRFD provides a consistent tool for updating the specifications as new data becomes available. This includes both better understanding of behavior and of loading.
7. *Loading*. With the requirements of different load factors for different types of loads, the designer must be more load conscious. With a 1.2 factor for dead load and 1.6 factor for live load, the designer must be sure of the categories into which the loads are assigned. The designer will be forced to better understand where loads come from and what variability can be expected.
8. *Economy*. Designs with the LRFD Specification may be more economical than ASD designs. This is particularly true when dead load dominates.
9. *Material interface*. The design interface for different materials, in particular steel concrete, will be enhanced with both materials following a similar format.
10. *Format*. International cooperation will be encouraged, since the format is consistent with that adopted by the International Standards Organization.

The list of advantages undoubtedly could be extended. There are also some disadvantages to adopting LRFD. Some of these will be identified to present a more balanced view and to recognize there have been honest concerns expressed:

1. *Change*. As always, change is difficult particularly on the part of experienced engineers who have developed a feel for the expected design under ASD.
2. *Software*. ASD computer software, which may represent a significant financial commitment, will be obsolete.
3. *Emphasis on theory*. It sometimes seems there is too much emphasis on the theoretical basis of LRFD and not enough on the practicality of design.
4. *Calibration*. LRFD is calibrated to a live-to-dead load ratio of 3.0. Thus, a big section of the steel marketplace perceives they may suffer under LRFD.
5. *Economy*. At present the economic incentives are too modest to induce change.

These disadvantages, and others sure to be identified, will eventually be put aside as time allows the practicing engineer to become more familiar with LRFD, and the universities begin to teach it to their students.

NEW EMPHASIS

Although the new specification is a complete change from ASD, many of the same concepts continue and new ones receive greater emphasis. There are two areas that are brought to the forefront which have considerable impact on introducing LRFD into the classroom. These are statistics and structural behavior. Both of these have been highlighted in the previous discussion of advantages and disadvantages.

Looking first at statistics, a new opportunity is found to use the work students have already put into their statistics courses. At first, this seems like a positive result; however, according to Myron Tribus in a recent article in *The Bent*,[11] less than 5% of new engineers graduating each year have had a course in statistics. Since this is the case, it is no wonder practicing engineers are concerned about the impact of a statistically based design specification. In addition, this means that along with teaching LRFD, some new work in statistics likely will need to be implemented.

It is difficult to visualize teaching structures without emphasizing behavior. However, with the push to reduce credit load while continuing to cover the same material, understanding behavior is often pushed aside in order to cover a breadth of topics. In this area, LRFD will provide a renewed push to deal with behavior. Unlike ASD, behavior is not hidden within the allowable stress and safety factor equations. Take for example, lateral torsional buckling. The limit state for this type of behavior is defined within the specification so it can be addressed independent of any other type of action. Column design, too, requires an extensive discussion of behavior, including such topics as stability and story buckling.

Much has already been written on the impact of LRFD on the resulting designs. Figure 2 shows a plot of the LRFD/ASD weight ratio for a pure tension member vs. live-to-dead load ratio. LRFD will provide a design with the resulting weight from 83% to 107% of the weight of the ASD design. The same size member will be obtained at a live-to-dead load ratio of 3. For bending, the comparison is more complex, depending upon how various designs are carried out; ASD, plastic, elastic LRFD or plastic

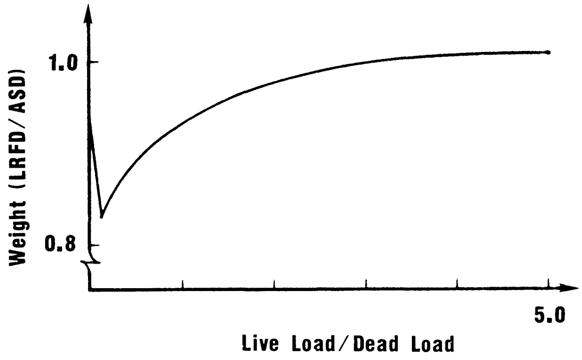

Fig. 2. LRFD advantage in tension member design

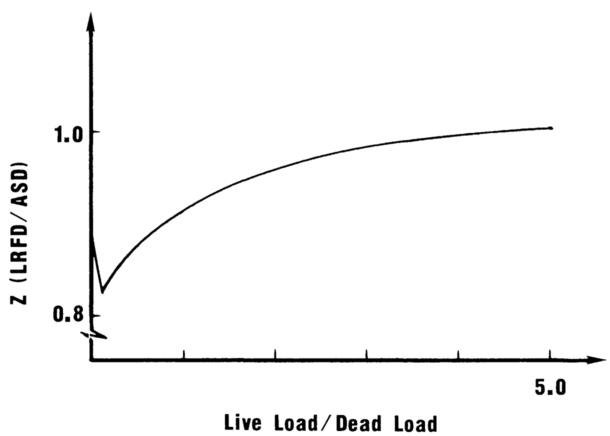

Fig. 3. LRFD advantage in bending design

LRFD. Taking one example, a two-span beam with 30-ft spans and a live-to-dead load ratio of 0.4, the allowable stress design yields a W18×55—while LRFD yields a W18×35. A plot of the ratio of required plastic section modulus for LRFD and plastic design vs. live-to-dead load ratio is shown in Fig. 3. It shows that LRFD could result in savings for live-to-dead load ratios below 5.0.

Serviceability will not normally be impacted by a change to LRFD. If serviceability criteria control, the final designs in both LRFD and ASD should be the same. One positive impact on serviceability, however, is the new focus on understanding what serviceability criteria really are. The potential for serviceability factors and system factors may, at some future date, bring LRFD to bear more strongly on serviceability.

WHAT CAN BE LEARNED FROM CONCRETE

It is common knowledge the specification for reinforced concrete, ACI 318,[1] has gone through some changes similar to the change from ASD to LRFD. We should be able to look back at those changes and learn something about the future for LRFD. A time line representing the evolution of reinforced concrete design according to the ACI code is presented in Fig. 4. In 1956, the ACI choose to include ultimate strength design (USD), provisions as an appendix to their allowable stress, called working stress, specification. Then, in the 1963 version of the code, USD and ASD shared equally with a direct correspondence of provisions. With the 1971 code, ASD became an alternate method, consisting of approximately one page of text. A number of modifications to the code have taken place since 1971, but none have been as extensive as the change from ASD to USD.

The middle bar of Fig. 4 represents the activity in the

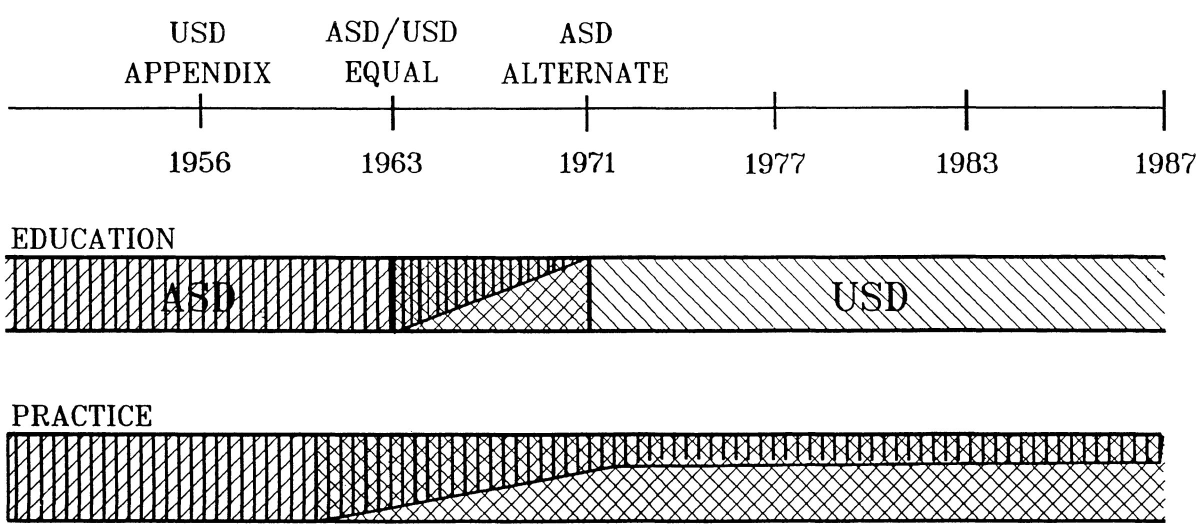

Fig. 4. Evolution of reinforced concrete design

educational community corresponding to the code changes. Up to 1963, undergraduate teaching was almost exclusively through ASD. Undoubtedly some faculty, closely associated with the changing code provisions, were introducing USD concepts. However, the majority continued with the proven approach. Around 1963, with the introduction of the new code and the availability of new textbooks, courses began to include topic coverage in both methods on a regular basis. It is interesting to note what Phil Ferguson said about the 1963 code in the preface to the second edition of his well known text.[8] The 1963 ACI code "closed much of the gap between rules of practice and the research knowledge of that date. Now explanations of the code are essentially explanations of basic theory, and specific research reports can often point up code philosophy." Similar comments have been made about LRFD and are the reasons LRFD will eventually be the dominant design approach. When the 1971 edition of the ACI code was published, the same incentive to teach both methods disappeared and most courses switched to USD. During the period of 1963 to 1971, however, there was a transition, as more time was given to USD and less to ASD, so this change was not really sudden. Since 1971, USD, or strength design, has taken over most applications. There are still some aspects of concrete design that use an elastic approach, such as prestressed members and serviceability, and these will likely continue.

The lower bar of Fig. 4 represents a similar picture for practice. The main difference being a wider range of dual use and continued use of ASD. This reinforces the need to understand the complete picture of behavior in order to know when to apply elastic principles and when to apply strength. The real question then is, what can be taken from concrete's evolution and projected to steel.

Figure 5 represents a similar analysis of the change from ASD to LRFD. The time line shows three key dates; 1978—the publication of the initial research papers already mentioned; 1983—the publication of the proposed LRFD specification and 1986—the publication of the final LRFD specification and manual. Again, the middle bar addresses the educational environment. Sometime prior to the issuance of the specification and subsequent to the publication of the proposed specification, LRFD concepts were being introduced into regular classes. As textbooks become available and faculty become more familiar with the new approach, more courses will include LRFD. As with concrete, a transition will take place, although a date for the complete change is not suggested. One factor which makes this transition different for steel than for concrete is the format chosen to publish the LRFD specification and manual. Since ASD and LRFD are in separate publications, it is going to be very difficult, and expensive, to teach both approaches. One possible solution will be to use a single manual, either ASD or LRFD, and supplement with the other separate specification. Faculty will need to use their initiative to incorporate both methods while keeping the cost to students within reason. Elastic stress approaches will continue to be a factor, even after complete conversion to LRFD, so as to address some of the serviceability requirements of design.

The lower bar of Fig. 5 represents the situation in practice. The profession was provided with a proposed specification in 1983 in order to help evaluate its provisions. Around that time, LRFD would have found its first applications to actual design for comparison and evaluation purposes. It has been suggested by Stan Lindsey that the first LRFD building to be built is the GAI office building in Nashville, Tenn., with design completed in March, 1987.[10] Perhaps the actual use of LRFD is not yet as widespread as suggested by the figure. If the sales of the LRFD

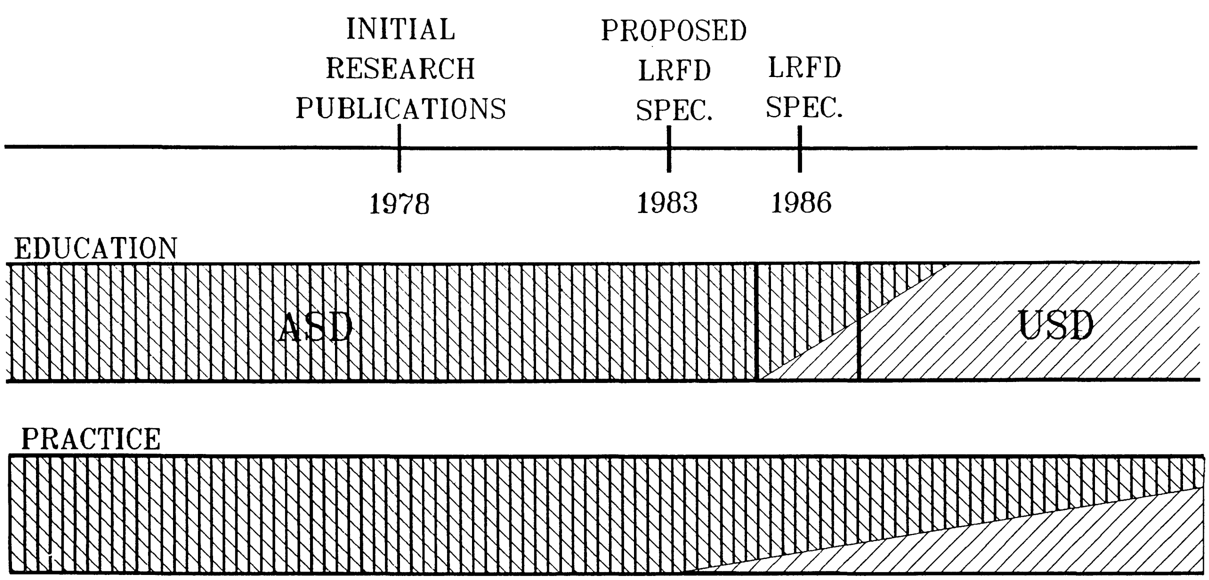

Fig. 5. Potential evolution of LRFD use

Manual are any indication, the profession is certainly interested in the new approach, with all of the first printing sold out in the first few months. As design professionals become more knowledgeable of LRFD through study and new graduates who have learned the methods in school find their place in the profession, use of LRFD on a daily basis will increase. Again, there will likely continue to be use of ASD in some components of the building industry, as there is for concrete, for some time to come.

THE PROPOSED SOLUTION

The time line presented in Fig. 6 shows this author's suggested options for moving toward inclusion of LRFD in a structural engineering curriculum. The first "activity" will show a lack of action. The majority of the academic programs will, over some period of time, ignore LRFD and continue to teach ASD. Many programs are already beyond this point and the remainder will be forced to address the subject by either a conscious decision to ignore LRFD or by moving into one of the other stages. The next stage will be the development of graduate level courses. It is in the graduate program where the most flexibility is available for the addition of new material. This author's experience with teaching LRFD in a graduate course during the Spring '87 semester has proven quite successful. It was an exciting course with the opportunity to bring in many new topics, with an emphasis on behavior and systems. At the 1987 AISC NEC/COP, an informal survey conducted at the educators program indicated approximately 40% of those faculty attending were already teaching LRFD at the graduate level.

After some experience with teaching a graduate course, faculty will begin to integrate LRFD concepts into ASD courses. The biggest drawback in combining the two approaches is the form in which the two are published, two completely separate publications. As faculty find ways around this drawback, integration will proceed. The transition, however, will not be as smooth as it was for concrete.

As new textbooks become available, a switch to a completely LRFD-oriented program will take place. At the same AISC conference mentioned earlier, 10% of the faculty indicated they taught LRFD to undergraduates. It was not determined whether this was in place of, or along with, ASD. It is clear that some already teach only LRFD in their undergraduate programs. Before all programs switch to LRFD, a great deal of feedback is going to be needed from the profession. The switch must be a joint effort. However, the students sent out into the profession will have the greatest impact. The future is in the hands of the educators.

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Fig. 6. Options for implementation of LRFD