Design of steel structures with load and resistance factor design specifications

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Design of Steel Structures with Load and Resistance Factor Design Specifications

Conception des structures métalliques et spécifications aux états limites

Neue Grenzzustands-Normen für Stahlbauten

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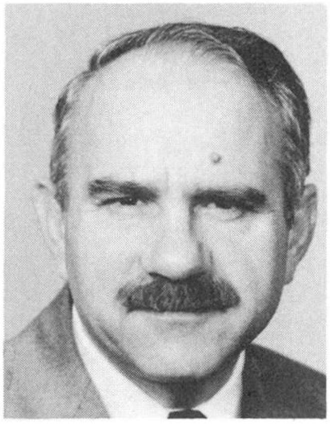

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SUMMARY

This paper describes the background and the major provisions of the new load and resistance factor design specifications for steel building structures.

RÉSUMÉ

Cet article décrit les bases et les points essentiels des nouvelles spécifications aux états limites pour les structures en acier.

ZUSAMMENFASSUNG

Dieser Artikel beschreibt die Grundlagen und die Hauptrichtlinien der neuen Grenzzustands-Normen für Stahlbauten.

1. INTRODUCTION

The Specification for the Design, Fabrication and Erection of Structural Steel for Buildings, issued and maintained by the American Institute of Steel Construcion (AISC) has been the pre-eminent steel design code in the United States of America since 1923. While it strictly applies for the design of building structures fabricated from hot-rolled steel components, it is clearly the model and the benchmark for all other steel design specifications used in the USA, and for codes in many other countries.

The current (1985) official version of the AISC Specification has two parts: Part 1 is nominally in an Allowable Stress Design (ASD) format, while Part 2 (Plastic Design) is in a Limit States Design (LSD) format. However, Part 1 is, in fact, also based on LSD principles which are disguised, sometimes quite transparently, to accommodate the traditional ASD format.

Research on the development of a separate and new LSD specification for steel building structures was initiated by the American Iron and Steel Institute (AISI) in 1969. The results of this work are culminated in the new (AISC) Load and Resistance Factor Design specification (LRFD) which will be issued in 1985. This paper describes this LRFD specification.

2. HISTORY OF THE DEVELOPMENT OF THE LRFD SPECIFICATION

The LRFD specification is based on LSD principles and the partial factors were determined by First-Order Second Moment (FOSM) probabilistic theory. It is entirely independent of the currently official (1985) AISC Specification, and decision theory was used as the basis for organizing its contents. It also contains a number of up-dated design procedures, notably for the design of beams, beam-columns and composite beams.

The initial research effort (1969-1978) culminated in a preliminary draft of the LRFD specification (1) and in a series of eight papers in the Sept. 1978 Journal of the Structural Division of ASCE which detailed the methods and the statistical data used to develop the criteria. This preliminary draft was not only the result of the effort of a number of specialists in probablistic design, decision theory logic, and structural steel behavior, but it also contained practical input from extensive trial designs performed in two consulting offices. In 1978 it was evident that 1) LRFD was a possible and desirable design method, but 2) the AISC LRFD specification could not function without a common basis for load and load factor determination which is shared by the structural design codes for all structural materials, especially reinforced concrete, masonry, aluminum and wood. As a consequence, the action shifted to the American National Standards Institute (ANSI) Committee on Building Code Requirements for Minimum Design Loads in Buildings which issued its load standard (2) in 1982. This standard contains the new load factors and load combinations to go with any building material, and its basis is the FOSM method, as detailed in a number of publications (3,4,5). The load factors were determined to give a target reliability index $\beta=3.0$ for gravity load, and $\beta=2.5$ for load combinations involving wind loads. The various material groups then were provided with a method to determine resistance factors to go with their respective design codes such that roughly the same reliability was achieved as implied by the load factors.

In the meantime various subcommittees of the AISC Specification Committee undertook to rework the LRFD draft, and the LRFD specification was approved in principle in 1981. A draft for review and trial was issued in 1983, and currently work is concluding on the final specification, including a commentary and a design manual.

3. FEATURES OF THE NEW SPECIFICATION

3.1 FORMAT

The format of the design inequality contains partial factors for load effects, γ, and for resistances, ϕ:

$$\phi_k R_{nk} \geq \gamma_D Q_D + \gamma_{Ei} Q_{ni} + \sum_{j=i}^{m} \gamma_{Ej}^{*} Q_{nj} \quad (1)$$

where the subscript n denotes nominal (code specified) values of the resistance R and the load effects Q, the subscript k denotes different applicable resistance limit states, the subscript D means dead load, and the subscript E defines the time-varying load effects due to occupancy, wind, snow, earthquake, etc. loads. The load factors for these latter quantities count on one of the time-varying loads to have its maximum life-time value (a 50 year life is assumed) while the others take on their arbitrary-point-in-time- values (3,5). Following is an array of some load combinations to illustrate the combinatorial process:

1.4D (2a)

1.2D + 1.6L + 0.5S (2b)

1.2D + 1.6S + 0.5L OR 0.8W (2c)

1.2D + 1.3W + 0.5L + 0.5S (2d)

D,L,S and W are dead, live, snow and wind load effects, respectively. The comparison with the corresponding load factors in the 1978 ECCS Code are shown in Table 1.

TABLE 1: LOAD FACTORS

A.I.S.C. CODE, 1985	E.C.C.S. CODE, 1978
1.33D+1.78L+.56S	1.3D+1.5L+.75S
1.33D+1.78S+.56L	1.3D+1.5S+.75L
1.33D+1.44W+.56(L+S)	1.3D+1.5W+.75(L+S)

3.2 ORGANIZATION OF THE LRFD SPECIFICATIONS

The specification provides the nominal resistance R_{nk} and the resistance factors ϕ_k for the various limit states appropriate to each type of member or connection. The resistance factors were determined by FOSM and they provide reliability index values from about 2.5 to 3.0 for members and 4.0 to 5.0 for connection under dead plus live loads.

The LRFD specification is organised as follows:

A. General Provisions.
B. Design Requirements.
C. Frames and Other Structures.
D. Tension Members.
E. Columns and Other Compression Members.
F. Beams and Other Flexural Members.
G. Plate Girders With Tension Field Action.
H. Members under Combined Stress, Torsion and Combined Stress and Torsion.
I. Composite Members.
J. Connections, Joints and Fasteners.
K. Strength Design Considerations.
L. Serviceability Design Considerations.
M. Fabrication, Erection and Quality Control.

4. DESCRIPTION OF SELECTED PROVISIONS.

Following is a brief discussion of selected provsisions of the LRFD specification so that comparisons can be made with the corresponding rules in the EUROCODE 3.

4.1 COLUMNS

One column formula is used in the LRFD specification for all types of compression members. The basis for it is an initial out-of-straightness of 1/1500 of the column height; end-restraint which results in an elastic effective length factor of 0.96 is assumed. The basic column curve (non-dimensional slenderness ratio -versus-critical stress ratio) is compared to the European column curve b in Fig. 1. The LRFD curve is seen to be above the European curve, especially in the intermediate slenderness range. It should be realized, however, that the resistance factors and the load factors are not the same for the two codes. With a resistance factor $\phi = 0.85$ and 1.0, respectively, for the AISC and the ECCS codes, it turns out that in most instances the latter is more liberal. For example, a permissible design force P of 670 kN and 706 kN is obtained by the AISC and SSRC method, respectively, for the following column:

W12 x 65, $F_y = 248$ MPa, Length = 4.57 m

$P_{dead} = P$, $P_{live} = P$, $P_{wind} = P/2$

4.2 PLASTIC DESIGN

Plastic design is permitted when the reference slenderness λ is less than or equal to a maximum plastic slenderness λpd. The comparative values of λpd are shown in Table 2 for the limits of flange buckling, web buckling and lateral-torsional buckling. The criteria are more liberal for the LRFD specification.

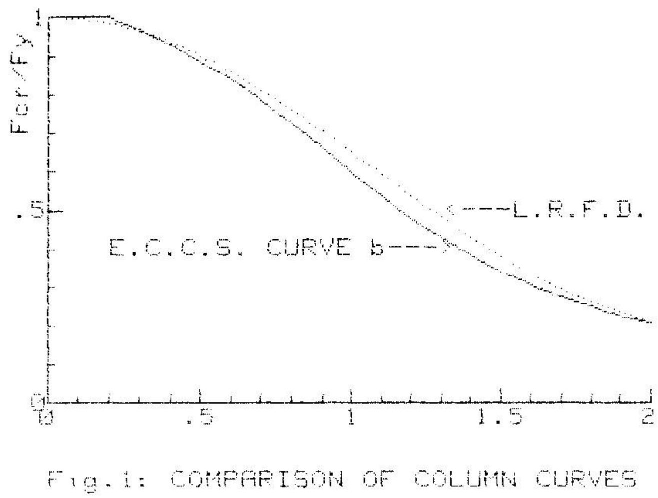


Fig.1: COMPARISON OF COLUMN CURVES

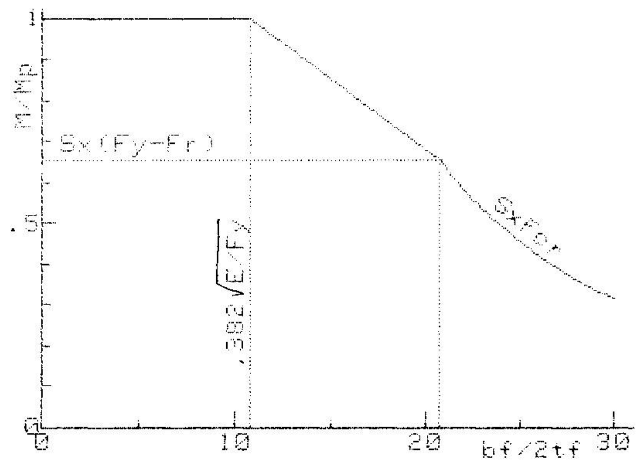


FIG. 2: LIMIT STATE FLANGE BUCKLING

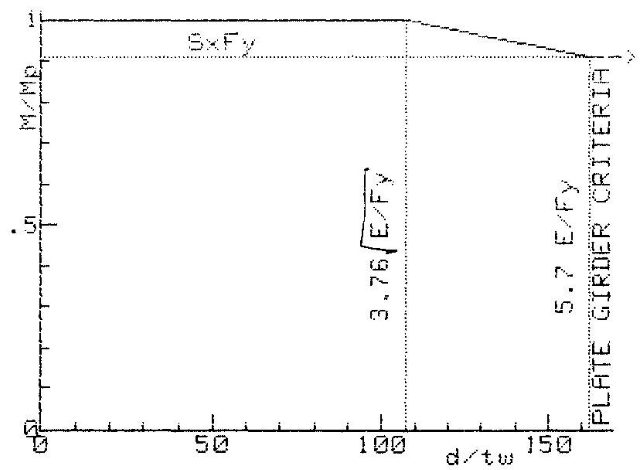


FIG. 3: LIMIT STATE WEB BUCKLING

TABLE 2: SLENDERNESS LIMITS: PLASTIC DESIGN

RATIO	LRFD LIMIT	ECCS LIMIT
$(bf/tf)/2$	$0.382\sqrt{E/Fy}$	$0.300\sqrt{E/Fy}$
d/tw	$3.76\sqrt{E/Fy}$	$2.4\sqrt{E/Fy}$
Lb/ry *	$0.048E/FY=40$ **	$1.37\sqrt{E/FY}=40$

* UNIFORM BENDING

** FOR $E/Fy=850$

4.3 BEAM DESIGN

When the forces in the structure are determined by elastic analysis, then beam design is governed by the limit states of flange local buckling (FLB), web local buckling (WLB), and lateral-torsional buckling (LTD) as shown in Figs. 2, 3 and 4, respectively. The limit state moment is the plastic moment, M_p, up to a slenderness λ_p, then a straight line transition in the range of inelastic buckling, and finally either the elastic buckling moment M_E (for FLB and LTB) or the moment including post-buckling strength (for WLB) controls for slender beams. For the limits FLB and LTB the change from inelastic to elastic buckling occurs when the stress equals the yield stress less a residual stress of 69MPa. The equivalent moment factor C_b is used to account for reduced yielding along the length of the member if the moment field is non-uniform, as shown in the construction of Fig. 4. The LRFD criteria tend to be more liberal, as seen by the example in Fig. 5.

4.4 BEAM-COLUMNS

Beam-columns are designed by a new set of interaction equations, illustrated here for major axis bending of wide-flange members:

$$\frac{P_u}{\phi_c P_{cr}} + \frac{8 M_u}{9 \phi_b M_{cr}} <= 1 \qquad \text{for } \frac{P_u}{\phi_c P_{cr}} >= 0.2 \quad (3a)$$

$$\frac{1 P_u}{2 \phi_c P_{cr}} + \frac{M_u}{\phi_b M_{cr}} <= 1 \qquad \text{for } \frac{P_u}{\phi_c P_{cr}} < 0.2 \quad (3b)$$

This interaction relationship is shown in Fig. 6. The symbols in the formulas are defined as follows:

1) $\phi_c = 0.85$ and $\phi_b = 0.9$ are the resistance factors for columns and beams, respectively.
2) P_{cr} is the critical column buckling load, including the effective length factor accounting for frame buckling.
3) M_{cr} is the critical beam moment-capacity of the member.

$$M_u = B_1 M_{nt} + M_t \tag{4}$$

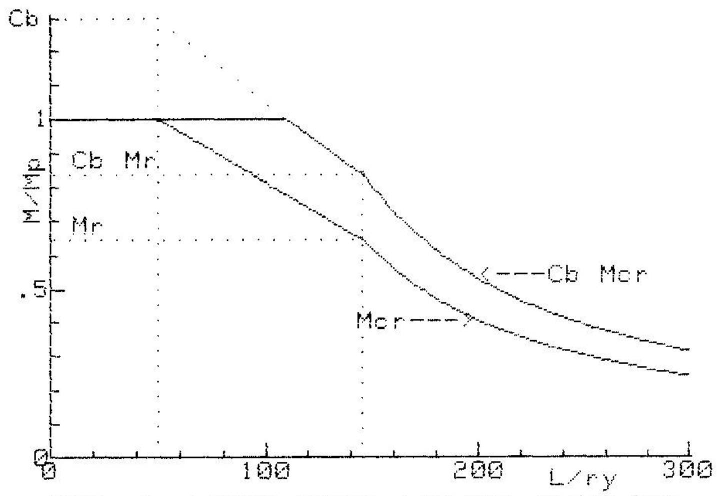
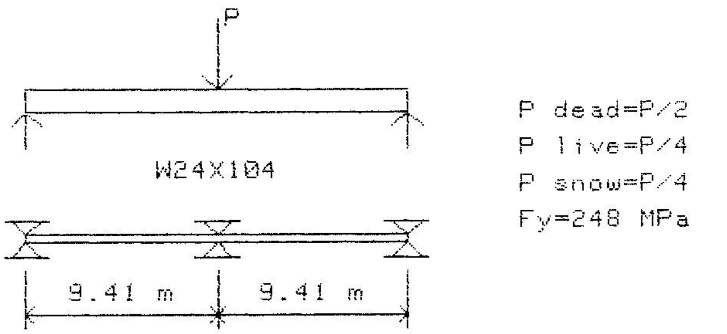


FIG. 4: LIMIT STATE LATERAL BUCKLING



PERMISSIBLE DESIGN FORCE: LRFD= 206 kN
ECCS= 186 kN

FIG. 5: BEAM DESIGN EXAMPLE

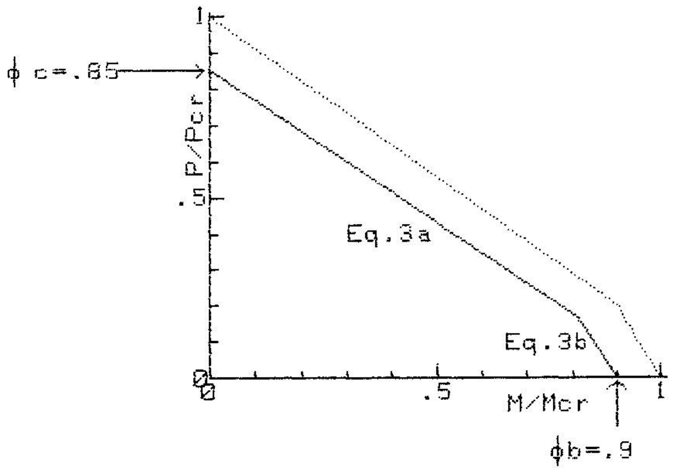


FIG. 6: INTERACTION CURVES FOR BEAM-COLUMNS

where

$$B_1 = \frac{C_m}{1-P_u/P_e} >= 1 \quad (5)$$

P_e is the elastic buckling load in the plane of the moment assuming no side-sway buckling and C_m is the equivalent moment factor. The moment M_{nt} is determined as if the joints were restrained from translation, and M_t is the moment due to lateral and restraining forces, including second order story translations. Approximate formulas are provided for the amplification of M_t if it is computed by first-order methods, but an actual second-order analysis is recommended.

5. CONCLUSION

This paper described the salient features of the new Load and Resistance Factor Design specifications of the AISC. Comparisons are made with the corresponding European code.

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