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COMPUTER AIDS for the DESIGN OF COLD-FORMED STEEL STRUCTURAL MEMBERS

by

Paul A. Seaburg[1]

Since it was first introduced in 1946, the Specification for the Design of Cold-Formed Steel Structural Members has grown both in volume and complexity. The latest, 1986 Edition(1), is the result of a significant updating to take advantage of the additional research in this area. The result, however, is that the use of this Specification has increased in difficulty as well. Design aids to simplify the process are vital. This paper discusses this with particular emphasis on computer aids.

Cold-Formed Steel Design Manual

The Cold-Formed Design Manual which accompanies the new Specification in itself provides a number of design aids. The Commentary to the Specification, contained in Part II, is the first of these. To the author's knowledge, the cold-formed design specification was the first such structural design specification to have a commentary. It has proven to be a very important way of clarifying the specification and also provides the user with an insight into its application.

Part III of the Manual provides supplementary information including a number of very useful formulas for calculating the properties of sections or their individual elements. The Illustrative Examples given in Part IV illustrate how to apply the Specification to specific problems. Part V provides a number of charts to reduce the need for calculations. The tables of section properties can be useful in selecting an appropriate shape or provide a rough check for calculations involving a reasonably similar shape. Finally the Computer Aids, provided in Part VI, help users develop programs to apply the Specification to several common problems. These will be discussed later. Thus the Design Manual provides the user with a initial set of useful design aids.

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Computer Applications

It becomes readily apparent to a repeated user of the Specification that software to apply these provisions is a must. The individual calculations involved in evaluating a cold-formed shape are in themselves numerous and tedious. The application of the effective width concept wherein element widths vary with calculated stress level requires that iterative approaches be applied. The 1986 Edition of the Specification has increased the complexity by applying effective width concepts to unstiffened compression elements and web elements in addition to stiffened compression elements. We are indeed fortunate that computer technology is here to help us with the complexities of modern design -- or is it the computer that made modern design complex? At any rate, the computer is very useful to those who apply the Specification on a regular basis.

Flow Charts

Part VI of the Design Manual consists of flow charts. These were prepared by Subcommittee 19-Computer Design Aids of the AISI Advisory Group. Most of these cover sections of the Specification selected because of the complexity of these particular sections. These are identified by the section on which they are based. The chart shown in Figure 1, for example, shows the provisions in Section B2.1 for determining the effective width of a uniformly compressed stiffened element for purposes of determining the load capacity. The chart provides a very clear picture of the items which need to be determined and the possible choices. Charts such as this apply directly to the computer programmer. They are also an excellent means of helping the user to understand the particular section provisions. Note that these charts apply only to the particular section identified but relationships to other Specification provisions are implied by references such as that shown for the determination of the term "k".

The flow chart illustrated in Figure 2 is unique. This presents an algorithm for determining the moment capacity of a flexural member. This recommends an initial assumption of the maximum compressive bending stress and the position of the neutral axis. This assumption permits consistent stress levels at other positions on the cross section to be calculated. The actual maximum compressive stress and location of the neutral axis are calculated during the process and compared in the final step to determine if the entire process must be repeated with a better assumption for these values. Flow charts of this type are essential to develop an overall computer program. More such charts would be useful for other common applications of the specification.

Decision Tables

Another computer design aid available from AISI is a complete set of decision tables. A decision table presents a concise display of all the elements pertinent to a problem. Applied to a specification, they provide an excellent means of showing the conditions covered and the actions to be taken on the basis of the specific conditions being considered.

The 1969 AISC Specification for the Design, Fabrication & Erection of Structural Steel for Buildings was presented in a decision table format in a technical report from the University of Illinois dated August, 1969(2). This report pointed out that the text of the AISC Specification had been written for use by experienced engineers. Absolute precision in the wording was not necessary since such persons are expected to be able to use their own judgement where necessary. Those producing computer programs, however, may have less capability and of course the programs produced have no such interpretive capability. The same situation is true today. Following this lead, the AISI sponsored a project to prepare the Decision Table Formulation of the Specification for the Design of Cold-Formed Steel Structural Members, 1968 Edition(3). New tables were recently prepared by AISI sponsored work at Midgley-Clauer Associate, Inc., Youngstown, Ohio(4).

Figure 3 shows a typical decision table from this latest revision. The tables are numbered and named to correspond to the Specification section which they cover. This table shows the criteria for evaluating bending of cylindrical tubular members according to Section C6.1. The data required to execute this table are described in the box above the table. An "X" indicates the item must be supplied by the user. Items covered in other locations of the Specification are referenced to these locations.

The decision table itself consists of four sections. The "condition stub" given in the upper left hand quadrant identifies the conditions applicable to this problem. The possible actions are given in the lower left hand quadrant known as the "action stub". The combinations of the conditions covered by the Specification are shown in the upper right hand quadrant designated as the "condition entry" by either a "Y" or "N" entry. The designation "Y" means this condition is true while "N" means it is not true. No entry means it is immaterial. Finally the lower right hand quadrant, known as the "action stub", defines the action to be taken by the position of the letter "Y". It is presumed the actions are executed in the order shown, hence terms in some actions refer to their values as determined in a prior action.

A decision table shows very clearly the conditions which apply and the possible resulting actions. Any particular column of condition entries and required actions constitute a "rule". Each rule would translate into an "if/then" statement in a program written in basic programming language. The complete set of tables thus provide an excellent aid in developing computer programs.

Another use of a decision table is to identify situations that are not covered. Considering each condition shown can be either true or not true, for "n" conditions, there are "n^2" possible combinations. This total number can be reduced by conditions that are immaterial. After accounting for these, all possibilities can then be studied to determine if some realistic combination is indeed overlooked by the decision table and hence the Specification.

Minimum Weight Design

One of the distinct advantages of working with cold-formed shapes is that they can be designed in an unlimited variety of configurations. The designer can create the shape with satisfies the functional need and evaluate its strength using the AISI Specification. Work sponsored by AISI in 1969(5) showed how cold-formed shapes could be optimized to serve their function with a minimum material weight. Figure 4 shows two sections typical of cold-formed steel products. The upper section is a single hat-shaped member which could be used as a beam or compression member. The lower profile represents a panel made up of repeating individual hat shapes. To define each of these shapes, it is necessary to specify seven dimensions, indicated in the figure as X_1 through X_7. The resulting shape must of course satisfy the structural requirements. This then becomes an optimization problem in which the objective is to chose these seven dimensions in such a way that all constraints of the AISI Specification are satisfied for a given set of loading conditions.

Problems of this type can be solved by systematically searching through the many possibilities. In the technique used this was done by using a gradient search approach which continually varies the dimensions such that the maximum reduction in required weight is achieved in each trial. The Specification requirements are used to determine the minimum acceptable thickness for any such set of the remaining dimensions. In optimization terminology, establishing the thickness in this manner causes the search to be confined to the constraint surfaces defined by AISI Specification provisions. The Fortran program developed at that time used all the applicable provisions of the 1968 Edition of the AISI Specification. The same approach could be updated to consider the 1986 edition.

The gradient search method is illustrated if figure 5. In this case, only the dimensions X_1, X_3 and X_7, i.e. thickness, are allowed to vary so that the search can be illustrated in a two dimensional plot. The figure shows possible values of X_1 and X_3 on the horizontal and vertical axes respectively. The contour lines designate the weight of the section as determined by the required thickness for the particular combination of X_1 and X_3. These contours are not generated by the computer search; they are added here only for illustration. The user chooses any starting point combination of X_1 and X_3. The search then proceeds until the minimum weight combination is achieved. Three starting points are shown in this figure. One search path also illustrates how the search is corrected when it continues too far in one direction, such as along the line segment DE.

The gradient search approach does not necessarily produce the same result for all starting points. This is because it terminates at local optimum points, that is, points immediately around which there are no better solutions. For this reason it is necessary to use a reasonable number of random starting points to increase the assurance that a global optimum has been achieved.

A further example of a minimum weight design produced in this manner is shown in figure 6. In this case the member illustrates a compression chord subject to both bending and axial load. The initial design resulting from an arbitrary starting point is shown in dotted lines; the final minimum weight design in solid lines. In this case a weight savings of 16 per cent was achieved.

Typical Existing Programs

Many companies that manufacture cold-formed shapes and consultants who specialize in this area have developed programs to fit their needs. Most of these programs calculate the section properties and load tables for a specific shape such as a C or Z shape. Some have developed more general programs that can handle any shape. In these programs, the section is defined by inputting the coordinates of the intersections of all tangent lines or some similar means. Such programs are far more complex because of the need to provide for all possible situations that might occur in the application of the program. Changes in Specifications have a significant impact on those who have invested in the preparation of such programs.

A number of consultants are available to assist users of cold-formed shapes. These persons can provide section properties and load tables for specific shapes and conditions. Some also market software packages for use by others. Subcommittee 19 of the AISI Advisory Group has recommended that software development be left to professionals working in this area.

The application of expert systems approaches is becoming very popular in engineering design. To the author's knowledge, this has not yet been done in the area of cold-formed steel design. It is certainly a valid area for possible future development.

References

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5. Seaburg, P.A. and C.G. Salmon, "Minimum Weight Design of Light Gage Steel Members", Journal of the Structural Division, ASCE, Volume 9, Number ST1, January, 1971.

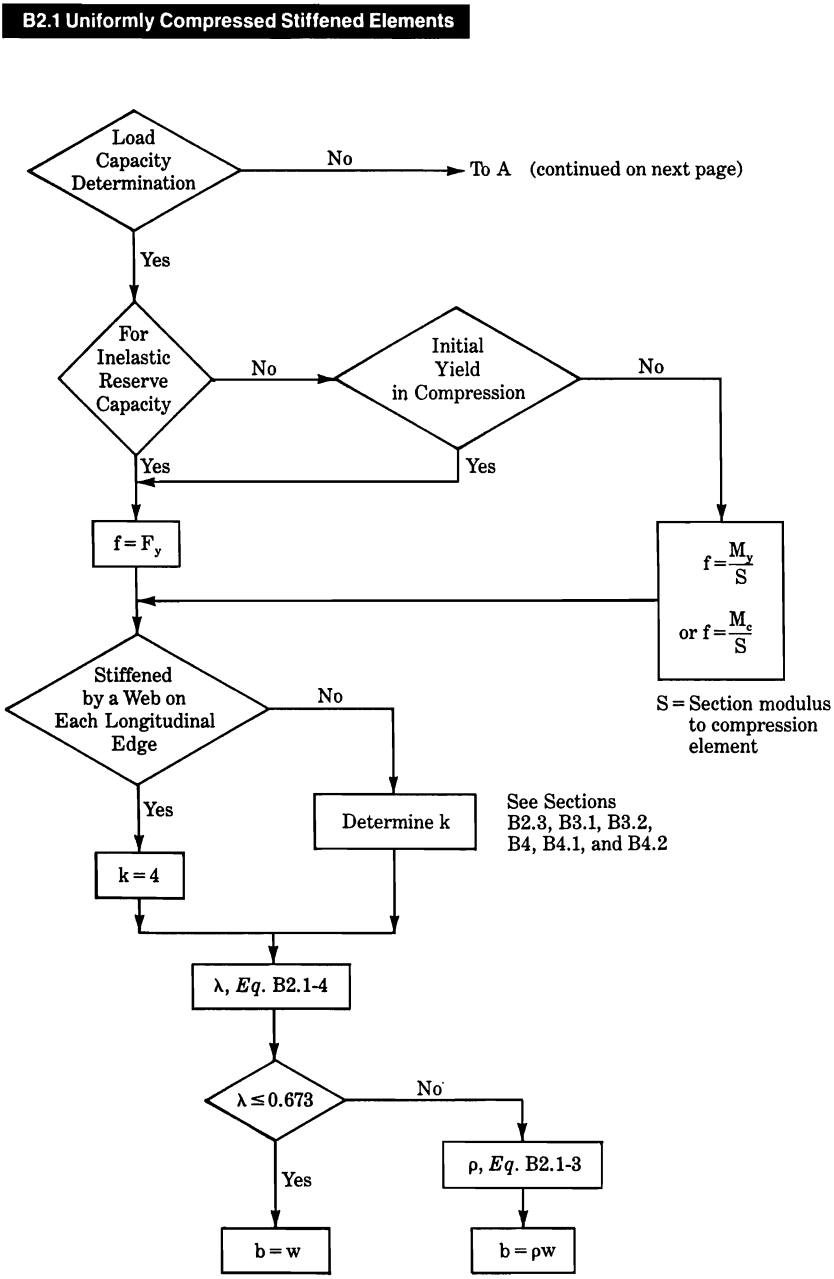
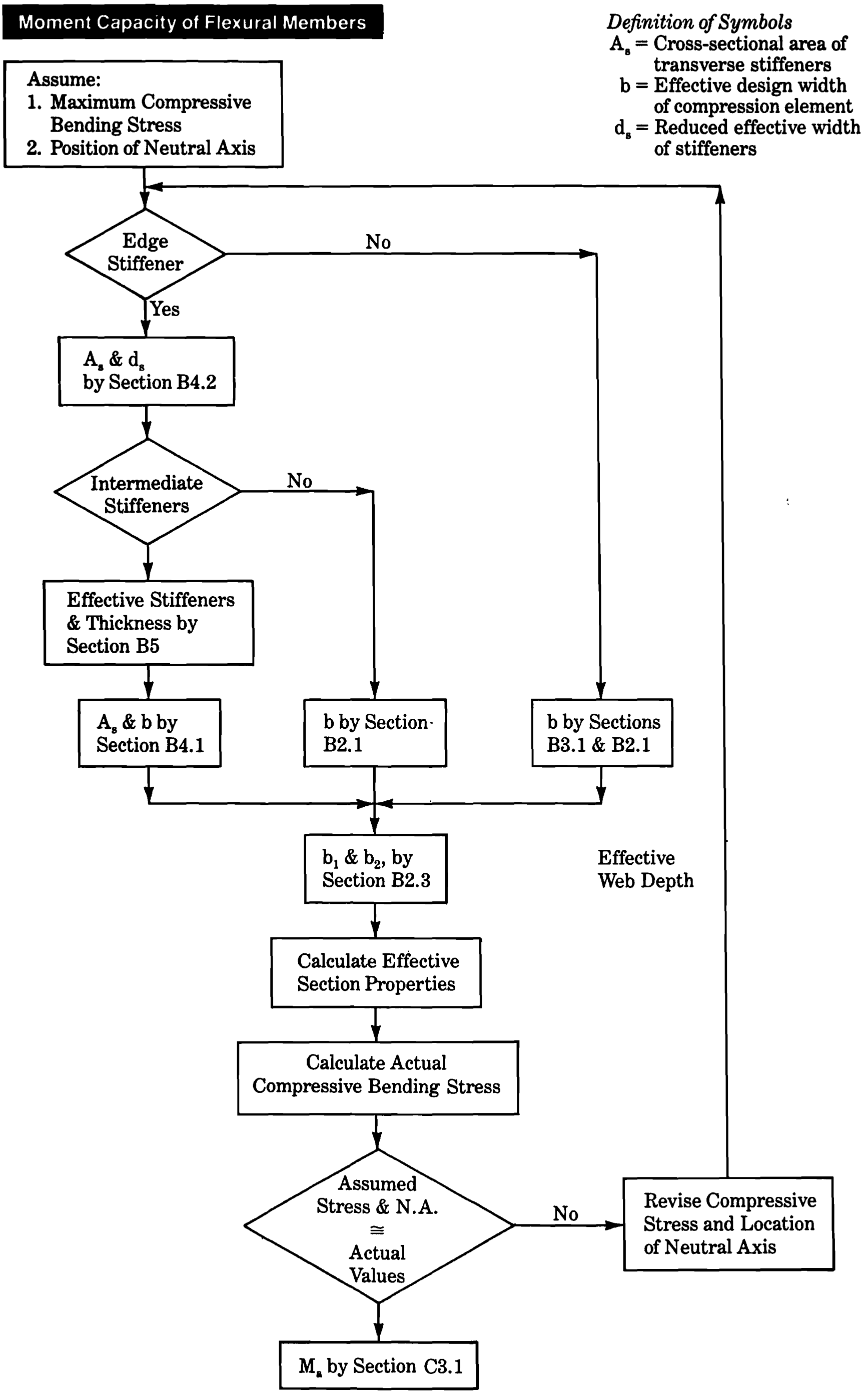


Fig. 1 Example Flow Chart from AISI Design Manual



Definition of Symbols

A_s = Cross-sectional area of transverse stiffeners
b = Effective design width of compression element
d_s = Reduced effective width of stiffeners

Fig. 2 Flow Chart for Moment Capacity from AISI Design Manual

TABLE C6.1.A BENDING OF CYLINDRICAL TUBULAR MEMBERS

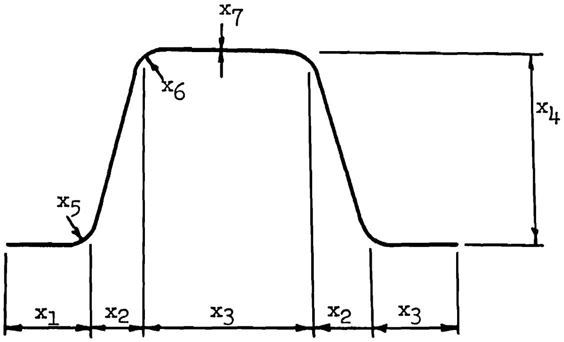
DATA REQUIRED

D, outside diameter	X	
t, wall thickness	X	
E, modulus of elasticity	X	
F_y, yield point		Table A5.2.A
S_f, elastic section modulus of the full cross section	X	

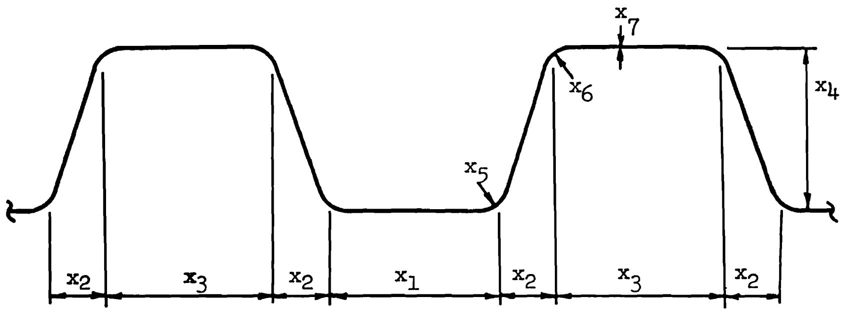
DECISION TABLE

$D/t \leq .070E/F_y$	Y		
$.070E/F_y < D/t \leq .319E/F_y$		Y	
$.319E/F_y < D/t \leq .441E/F_y$			Y
$M_n = 1.25F_yS_f$	Y		
$M_n = [.970 + .020(E/F_y)/(D/t)]F_yS_f$		Y	
$M_n = .328ES_f/(D/t)$			Y
$\Omega f = 1.67$	Y	Y	Y
$M_a = M_n/\Omega f$	Y	Y	Y

Fig. 3 Example Decision Table



a. Single Hat Shaped Member



b. Hat Shaped Panel

Fig. 4 Hat-Shaped Light Gage Steel Members

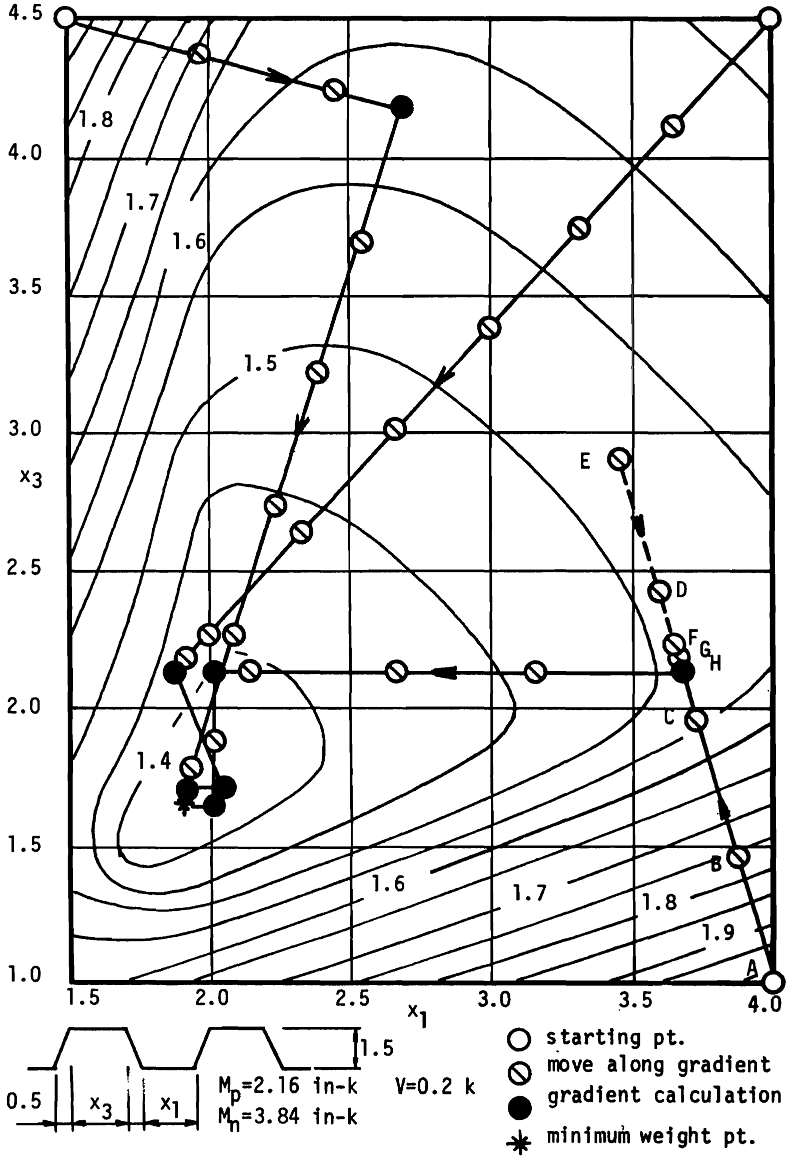
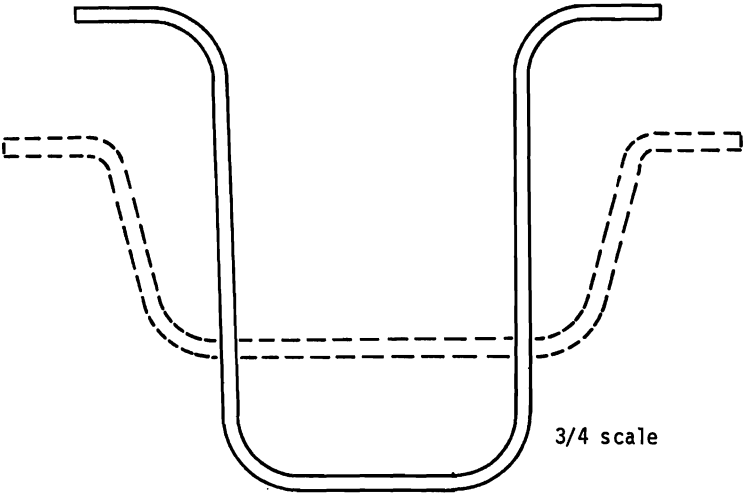


Fig. 5 Two Parameter Gradient Search for Hat-Shaped Panel



– – – Initial design
Required thickness = 0.172 in
Weight = 5.7 lb/ft

═ Final design
Required thickness = 0.105 in
Weight = 4.8 lb/ft

Design Conditions

Axial load = 34 kips
Moment at panel point = 3.3 in-kips
Moment at center of panel = 1.6 in-kips
Shear = 0.4 kips
F_y = 50 ksi C_m = 0.85
maximum radii = 5/8 in

Effective lengths:
vertical axis - 6 in
horizontal axis
at center - 48 in
at panel pt. - 24 in

Fig. 6 Example Minimum Weight Design of Compression Chord