

SELECTED BIBLIOGRAPHY
on
PLASTIC DESIGN
for
STRUCTURAL ENGINEERS

Report to ASCE Task Committee on
STRUCTURAL DESIGN METHODS

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ABSTRACT

This paper gives a "first reading list" to help the design engineer become familiar with available literature on plastic design in steel. Selected references on fundamental theory, experimental verification, and practical applications are included. A brief description of each reference is presented.

1. DISCUSSION OF RECOMMENDED READING

1.1 Introduction

Plastic design of welded continuous steel structures is a modern structural design method which has been developed to the state of practical application in the past decade. In this paper will be presented a "first reading list" to help the design engineer become familiar with available literature on the subject of plastic design. Under "General References" will be listed books and articles which describe the concepts, theory, and application of plastic design with a general coverage. Additional references are listed for specific topics such as: frames, columns, connections and deflection.

To gain a working knowledge of plastic design, a design engineer must first become familiar with the concepts of plastification of cross section and redistribution of moment which are possible due to the ductility of steel above the elastic limit in continuous structures. Then a knowledge of the upper and lower bound theorems may be applied to determine the ultimate loads of continuous beams or frames. Two important methods for the analysis of frames are the equilibrium or statical method and the mechanism method. The use of a uniform load factor relating working loads on the structure to the ultimate carrying capacity of the structure permits the selection of structural members to provide all applicable

structures with an equal factor of safety against ultimate load. Information on the proportioning and detailing of connections adequate to allow the structure to behave as predicted by the plastic theory is also necessary. With the addition of information on beam and column stability and problems in deflections, the designer will have in hand the basic fundamentals for proceeding with routine plastic designs. Experimental verification of most of the theories relating to plastic design is available to those who wish to see such proof.

1.2 General References

For first reading, three books are recommended. These are the "COMMENTARY ON PLASTIC DESIGN IN STEEL", the AISC Manual "PLASTIC DESIGN IN STEEL", and one of the textbooks listed.

The textbooks derive the theories involved and present methods of solving problems in a manner suitable for classroom instruction. The books by Beedle and Hodge are oriented towards American practice whereas those of Baker, Heyman, and Neal are written primarily for British engineers.

The AISC Manual presents some theory and concentrates on design examples in a form suitable for design office reference and also presents design charts and tables for many typical cases of continuous beams and single-story rigid frames. It also incorporates the "Rules for Plastic Design and Fabrication" adopted by AISC.

The "COMMENTARY" documents the applicability of plastic analysis to design of structural steel beams and frames. Theoretical considerations involved in the plastic theory and in secondary design problems are given. Approximations in the form of "design guides" are suggested. This joint committee report of ASCE and the Welding Research Council is intended to give the background on plastic design methods and the specification clauses which govern the application of plastic design. It gives an extensive listing of references on topics related to plastic design.

The articles listed under "General References" are shorter papers which were prepared for technical meetings or technical journals to present general information about the theory and application of plastic design and to describe its advantages. Any one of these articles will give the engineer a brief description of the theory, experimental verification, or possible practical applications of plastic design. Reference 13 describes a series of experimental demonstrations carried out to show the verification of most of the principles of plastic design. The two bulletins listed as Ref. 17 give the basic principles of plastic design as oriented toward British practice.

1.3 Articles on Frames

Articles with the specific topic of plastic design of steel frames are included in Ref. 18 to 23. References 21

and 22 describe the preparation of general design charts for single and multi-span one-story, pinned-base frames and present charts for a number of design situations. References 18 and 23 describe full-scale tests of welded rigid frames. Reference 19 presents design examples based on charts given in Ref. 21. A news article describing an actual warehouse project in which savings were realized by the use of plastic design is presented in Ref. 20.

1.4 Columns

References 24 and 25 describe in considerable detail the theoretical method for determining the ultimate load and moment-curvature relationship for columns under combined bending and thrust. These are not procedures which will be included in design office routines. The references are listed to give the engineer the opportunity to study the theoretical basis for the column design curves which will actually be used.

1.5 Connections

Reference 26 gives theoretical analysis and sample designs of square corner connections for rectangular portal frames. Reference 27 covers the analysis and design and test results on welded interior beam-to-column connections such as might be found in buildings of two or more stories.

1.6 Deflections

Reference 28 presents several exact and approximate theoretical methods of calculating deflections of structures in the plastic range. These methods are compared with each other and with tests to determine their accuracy.

2. ABSTRACTS OF REFERENCES

2.1 General References - Books

1. ASCE-WRC Joint Committee

COMMENTARY ON PLASTIC DESIGN IN STEEL
ASCE Manual No. 41, 1961

This report documents the applicability of plastic analysis to the design of structural steel beams and frames. Theoretical considerations involved in the plastic theory and in certain secondary design problems are given. Experimental verification is provided. Approximations in the form of design guides are suggested. Chapters on compression members, connections, and deflections are included.

A separate and companion report (2) illustrates the procedures of the plastic method of design with specific reference to building construction, and contains supplementary specification clauses permitting the use of plastic design for appropriate structures.

2. AISC

PLASTIC DESIGN IN STEEL, AISC, New York, (1959)

This manual illustrates the plastic design method by numerical examples that practicing engineers will find easy to follow. It covers simple plastic theory, methods of analysis, bending with axial load, shear and web crippling, bracing requirements, and haunched connections. Eighteen design examples are presented with detailed calculations for structures such as continuous beams, single-span and multi-span rigid frames.

The appendix contains the Rules for Plastic Design and Fabrication adopted by AISC in December 1958. In addition the appendix contains design charts and tables for continuous beams and single- and multi-span flat-roof and gabled frames with pinned bases. These are based on Ref. 21 and 22. A section economy table of plastic moments is also included.

3. L. S. Beedle, B. Thurlimann and R. L. Ketter

PLASTIC DESIGN IN STRUCTURAL STEEL, Summer Course
Lecture Notes, Lehigh University, Bethlehem, Penna.,
and AISC, New York, 1955.

The fundamental concepts of plastic analysis are presented in fourteen lectures. Specific plastic design techniques are described together with examples to illustrate their application. At the end of each lecture such reference as are appropriate to the topic are given. A list of general references is also included at the end of the notes.

These lectures were supplemented by a series of demonstration tests of actual structures described in Ref. 13.

4. J. F. Baker, M. R. Horne and J. Heyman

THE STEEL SKELETON, Vol. 2, Cambridge University
Press, Cambridge England, 1956.

The work of the research team at Cambridge is described. This work was instrumental in gaining the acceptance of plastic design in England even before this was accomplished in the United States. The book accomplishes its purpose by describing experimental tests and then developing the basic theories of plastic design from the results and observations. In this manner, the fundamental concepts and their application to design are derived. Descriptions of the application of plastic design to wartime and postwar structures are given. The topic of minimum weight design of structures is covered.

5. Lynn S. Beedle

PLASTIC DESIGN OF STEEL FRAMES, John Wiley and Sons,
New York, (1958)

This book presents the principles and methods that are the basis for plastic design and shows how they may be used in the solution of practical building frame design problems. It was written for students of structural engineering - those in colleges and universities on the one hand, and those in engineering practice on the other. As a consequence, the first six chapters present the fundamental concepts and the methods of analysis and design; numerous examples are included for illustration, and problems are provided for the student. A summary prepared from a design point of view is given in Chapter 7, together with "general provisions" for materials, fabrication, loads and forces, and the load factor. Design examples of beams and frames are then given in Chapters 8 and 9 to illustrate the principles and methods of the earlier chapters.

6. J. Heyman

PLASTIC DESIGN OF PORTAL FRAMES, Cambridge
University Press, Cambridge, England, (1957)

This short book discusses in detail the plastic design of single-story pitched-roof portal frames together with their associated system of purlins and girts. As well as presenting the basic principles of plastic design, an attempt is made to give the results of detailed experience with this type of structure in Great Britain.

Column design charts and tables of plastic modulus for British Standard sections are included.

7. Philip G. Hodge, Jr.

PLASTIC ANALYSIS OF STRUCTURES, McGraw-Hill Book Company, New York, (1959)

The book is primarily a textbook. Part I on beams and frames contains a reasonably comprehensive treatment of the application of plastic methods to frame-type structures whose principal strength lies in their resistance to bending. The final Chapter in Part I considers frames structures where tensile stresses produce both an axial force and a bending moment; it serves as a transition to the combined-stress problems of Part II, where combined stresses in beams, circular plates, circular cylindrical shells and problems in plane stress are covered. Finally, the book closes with a brief introduction to some of the problems encountered in the dynamic loading of plastic structures. In part II a knowledge of differential equations is necessary.

8. B. G. Neal

THE PLASTIC METHODS OF STRUCTURAL ANALYSIS
John Wiley & Sons, Inc., New York, 1956

The book introduces the principles of plastic design without introducing higher mathematical operations. In addition to its coverage of the fundamentals of plastic analysis, this book includes articles on plastic moment distribution, minimum weight design, and variable repeated loading.

A table of the plastic moduli of British Standard Beams is included in an appendix.

2.2 General References - Articles

9. L. S. Beedle

ON THE APPLICATION OF PLASTIC DESIGN, Proceedings of the Second Symposium on Naval Structural Mechanics, (entitled Plasticity). Office of Naval Research Structural Mechanics Series, Pergamon Press, 1960

This paper presents a general survey to show how plastic design has been applied in the United States and to indicate the extent to which the advantages claimed for it have influenced its use. Several plastically designed structures are shown. The reasons plastic design was used and the savings as compared with elastic designs are discussed. The current work on some research problems and future trends in the application of plastic design are given. These problems include design of multi-story frames, use of high-strength bolts, development of composite action, frame stability problem, columns in rigid frames, bridges and ship structures.

10. L. S. Beedle

PLASTIC DESIGN OF STEEL STRUCTURES, AISI Regional
Technical Meeting, Philadelphia (November 1958)

It is pointed out that continuous structures have many advantages over those of simply-supported construction. The plastic strength of structural steel and the concept of plastic hinges are reviewed briefly. Then several examples of plastically designed structures are described.

This paper contains the text and illustrations from a lecture given before a group of technical men having a wide range of interests in the field of iron and steel applications.

11. L. S. Beedle

PLASTIC STRENGTH OF STEEL FRAMES, ASCE Proceedings Separate 532, Vol. 80, (August 1955).
Trans. ASCE Paper 2901, Vol. 122, P. 1139 (1957)

In order to demonstrate the applicability of plastic analysis to structural design in steel, the results of large-scale experiments are examined on the basis of theoretical predictions and correlated with current (1955) design specifications. The fundamentals of plastic analysis are described briefly. It is shown that the design of ordinary structural frames may be based on the maximum load the structure will support, as against the conventional methods which are based on the load at first yield. Although this paper does not purport to be a complete review of current investigations into the behavior of steel structures loaded beyond the elastic limit, sufficient evidence is presented to show that in many instances design may properly be based on maximum strength.

12. L. S. Beedle

PRACTICAL APPLICATIONS OF PLASTIC DESIGN IN
STRUCTURAL STEEL, Proceedings, Structural
Engineers Association of California, (October 1955)

Basic principles of plastic design are given. The equilibrium and mechanism methods of analysis are illustrated by examples. Three design examples of gable frames with or without haunches are given and the members selected are compared with those selected by elastic design.

The possible use of models in plastic design is described. The paper tells of a special device designed to simulate the action of plastic hinges and help visualize the formation of mechanisms in a two span gabled frame.

13. G. C. Driscoll, Jr., and L. S. Beedle

THE PLASTIC BEHAVIOR OF STRUCTURAL MEMBERS AND FRAMES, Welding Journal, 36(6), p. 275-S (1957)

This report describes a comprehensive series of demonstration tests which were performed to illustrate the plastic behavior of basic structural members and frames. The results of tests gave good agreement with the simple theory on which plastic design is based. Flexure and buckling tests were made on simple beams, a flexure test was made on a continuous beam, and short columns were subjected to combined bending plus axial load. A test was made on a full size welded connection of the type found in industrial buildings. Also, a complete gabled portal frame was tested to its ultimate load. The results of these tests lend the most convincing arguments that the maximum strength of structures may be predicted with sufficient accuracy to allow plastic design to be used with safety and confidence.

14. R. L. Ketter and B. Thurlimann

CAN DESIGN BE BASED ON ULTIMATE STRENGTH?
Civil Engineering, 25(1), p. 59 (January 1955)

A brief description of the moment-curvature diagram of mild steel members and the principles of plastic behavior of structures is given. The paper then demonstrates the simplicity of applying the plastic design concept by examples of a continuous beam and a portal frame. Advantages of plastic design are listed.

15. F. S. Merritt

HOW TO DESIGN STEEL BY THE PLASTIC THEORY,
Engineering News Record, Vol. 158, p. 38
April 4, 1957

A brief article with detailed sketches describes the fundamentals of the plastic theory and explains the mechanism method of analysis.

Continuous beams with uniform load, a pin-ended portal frame and a gable frame subjected to horizontal and vertical load are analyzed by the mechanism method. The method of instant centers and the influence of axial force are discussed.

16. B. Thurlimann

PLASTIC DESIGN OF STRUCTURAL STEEL, The
Engineering Journal, Canada (February 1957)

This is a paper read at a conference on "Plastic Design of Steel Structures" at Kingston, Ontario. It briefly covers theoretical implications, practical developments and plans for application in the immediate future in the United States.

17. British Constructional Steelwork Association

THE COLLAPSE METHOD OF DESIGN, BCSA Publication
No. 5, BCSA, 1952

Partridge, F. A.

THE COLLAPSE METHOD OF DESIGN AS APPLIED TO
SINGLE-BAY FIXED-BASE PORTALS, BCSA Publication
No. 11, BCSA, 1957

Two bulletins give an outline of plastic design theory and its application to the design of continuous beams, rectangular pinned-base portals, ridge-type pinned-base portals, and single-bay fixed base portals. About twenty complete design examples are presented. These are analyzed mainly by the statical or equilibrium method. The articles are oriented to British design and construction practices.

2.3 Frames

18. G. C. Driscoll, Jr.

TEST OF TWO-SPAN GABLED PORTAL FRAME, Proceedings, AISC National Engineering Conference, P. 74 (1956)

A large-scale test frame fabricated from 10B17 and 8B13 rolled shapes was loaded to ultimate load with a combination of vertical and horizontal forces. The load versus deflection curve of the frame is compared with the theoretical prediction.

19. E. R. Estes, Jr.

DESIGN EXAMPLES, Proceedings 1956 AISC National Engineering Conference, p. 58 (1956)

This paper describes the design office calculations required for the design of multi-span frames using special charts.

A two-span gable frame and a frame having gabled center span with flat roofed lean-to's on each side are designed using charts developed in Ref. 21.

Similar charts are available in Ref. 2.

20. E. R. Estes, Jr.

PLASTIC DESIGN OF WAREHOUSE SAVES STEEL, Civil
Engineering, 27(9), p. 608 (September 1957)

This paper presents the plastic design of the Dalton Company warehouse which was built in Sioux Falls, S. Dak. Frames of the warehouse were 88 ft. spans of the pinned-base gabled-roof type. Savings of approximately 13 percent in structural steel resulted from the plastic design as compared with a comparable elastic design. The details of corner connection and lateral bracing system are shown. Comments about the field erection point out that field welding and erection of the structural steel took only three working days.

A summary of design formulas for pinned-base and fixed-base single-span frames is also included in the paper.

21. R. L. Ketter

PLASTIC DESIGN OF PINNED-BASE GABLE FRAMES,
Welding Research Council Bulletin Series, No. 48,
(1959)

After listing the basic assumptions of plastic analysis, this paper presents a method whereby complex multiple span pinned-base gable frames can be readily designed. Design curves based on the mechanism method of analysis are presented. By using the design curves, member size and location of plastic hinges can be determined quickly. Four design examples of single-span, two-span and three-span frames are given. A discussion of methods of approaching minimum weight designs is included.

Design charts based on this paper have been included in Ref. 2.

22. R. L. Ketter and B. T. Yen

PLASTIC DESIGN OF PINNED-BASE LEAN-TO FRAMES,
Welding Research Council Bulletin Series, No. 53,
(1959)

This paper extends the method of Ref. 21 to the design of pinned-base "lean-to" type structures. Design equations and curves are derived and presented for additional cases.

Design examples of a three-span mill building with sloping lean-tos' and a multi-span saw-tooth frame are given to illustrate the method.

23. C. G. Schilling, F. W. Schutz, Jr. and L. S. Beedle
BEHAVIOR OF WELDED SINGLE-SPAN FRAMES UNDER
COMBINED LOADING, Welding Journal, 35(5) p. 234-S
(1956)

The results of tests carried out on two full-size portal frames are presented. These frames were of welded construction and had spans of 30 ft. and column height of 10 ft. The column bases were pin-ended in one case and fixed in the other. The frames, which were fabricated from 12WF36 shapes, were subjected to simultaneous application of vertical and horizontal loads. The behavior of the component parts of the frames (beams, columns, welded connections) as indicated by various measuring techniques are compared with computed values based on simple plastic theory. Attention was given to the problem of plastic instability. The lateral forces required to restrain the frames to their original plane were measured and analyzed. These forces are of significance in both elastic and plastic design of such structures. Information with regard to the action of fixed base frames under very high horizontal loads is presented.

2.4 Columns

24. T. V. Galambos and R. L. Ketter

COLUMNS UNDER COMBINED BENDING AND THRUST, ASCE
Proceedings Paper 1990, Vol. 85, EM2(1959)

Interaction curves relating the axial thrust, applied end bending moment and slenderness ratio are developed for the ultimate carrying capacity of pin-ended, wide-flange beam-columns. It is assumed that failure is due to excessive bending in the plane of the applied moments which is further considered to be the plane of the web. The two conditions of loading that are investigated are (1) equal end moments applied such that the resulting deformation is one of single curvature, and (2) end moment applied only at one extremity of the member. The influence of an assumed symmetrical residual stress pattern is considered in the calculations and curves are presented for slenderness ratios up to and including $L/r = 120$. For ease of future computation, the interaction curves are fitted into approximate equations. Comparisons are made with various column test results.

25. R. L. Ketter, F. L. Kaminsky, and L. S. Beedle

PLASTIC DEFORMATION OF WIDE-FLANGE BEAM-COLUMNS
Transactions of the ASCE, 120, p.1028 (1955)

Presented in this paper are the results of an analytical and experimental study of the inelastic deformations of wide-flange steel beam-columns. Emphasis has been directed toward the influence of axial thrust on the moment-curvature ($M-\phi$) relationship when stresses exceed the elastic limit. The analysis is extended to include the influence of residual stresses, and thus the moment-curvature relationship is developed as a function of axial thrust and residual stress. Buckling loads are then determined for eccentrically loaded steel columns of WF shape, the necessity for an assumed 'shape factor' being eliminated. These derived moment-curvature relationships are also applied to determine column end rotations and mid-height deflections. Two sizes of WF shapes are considered, (8WF31, 4WF13) and in the experimental studies, tests were carried out on as-delivered WF structural sections.

2.5 Connections

26. J. W. Fisher, G. C. Driscoll, Jr. and L. S. Beedle

PLASTIC ANALYSIS AND DESIGN OF SQUARE RIGID FRAME
KNEES, Welding Research Council Bulletin Series,
No. 39, (April 1958)

This paper contains sample calculations and a description of the plastic design of a square knee for a single-span rigid frame. Welds are designed using the concepts of plastic design as well as those of elastic design in order that the parallelism can be seen. The methods of design presented here can be used as a guide in designing comparable connections for rectangular portal frames. A theoretical analysis of a straight knee with diagonal stiffeners is also presented and leads to expressions for the reinforcement required within the knee to prevent undue deformation. A further analysis is made of the rotation and deflection of the connection.

27. J. D. Graham, A. N. Sherbourne, R. N. Khabbaz
and C. D. Jensen

WELDED INTERIOR BEAM-TO-COLUMN CONNECTIONS, AISC
(1959). Also published in Welding Research Council
Bulletin Series No. 63 (1960)

This report is a summary of experimental and analytical investigations into the behavior of connections both with and without stiffeners. The first stage of this work comprised an investigation into two-way beam-to-column connections, first by detailed tests copying practical conditions and later by simpler tests simulating these conditions. The second stage comprised an investigation into four-way beam-to-column connections, again by detailed tests copying practical conditions. Design rules for connections of fully-loaded beams to column flanges are given. Design examples follow.

2.6 Deflections

28. K. E. Knudsen, C. H. Yang, B. G. Johnston and
L. S. Beedle

PLASTIC STRENGTH AND DEFLECTIONS OF CONTINUOUS
BEAMS, Welding Journal, 32(5) p. 240-S, (1953)

This paper demonstrates several methods for computing deflections due to bending of mild steel beams of uniform cross section. The effect of various simplifying assumptions which greatly reduce the numerical work involved is shown together with comparison with experimental results. The influence on the deflections of various degrees of end restraint and load distribution is computed.

The paper demonstrates for several loading conditions on continuous beams the possible savings by using plastic design as against conventional elastic design and suggests a specific design criterion applicable to the examples given.

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Mr. Yu-Chin Yen assisted with the assembly of the reference lists and preparation of abstracts. In many cases portions of abstracts published with the listed reference have been used in this paper. The author gratefully acknowledges the work of those authors in preparing abstracts suitable for this paper.

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