UILU-ENG-73-2025

IL ENGINEERING STUDIES
TURAL RESEARCH SERIES NO. 405
Cooperative Highway Research Program
No. 145

FATIGUE DATA BANK AND DATA ANALYSIS INVESTIGATION

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Project IHR-64

Prepared as a part of an investigation conducted by
THE CIVIL ENGINEERING DEPARTMENT
ENGINEERING EXPERIMENT STATION
UNIVERSITY OF ILLINOIS AT URBANA-CHAMPAIGN
in cooperation with
THE STATE OF ILLINOIS
DEPARTMENT OF TRANSPORTATION
DIVISION OF HIGHWAYS
and
THE U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL WORKS ADMINISTRATION

UNIVERSITY OF ILLINOIS
URBANA-CHAMPAIGN, ILLINOIS
JUNE 1973

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
UILU-ENG-73-2025		

4. Title and Subtitle	5. Report Date / 6. Performing Organization Code
Fatigue Data Bank and Data Analysis Investigation	5. Report Date: June 1973 6. Performing Organization Code:
7. Author(s) J. B. Radziminski, R. Srinivasan, D. Moore, C. Thrasher and W. H. Munse	8. Performing Organization Report No. SRS 405 ICHRP No. 145
9. Performing Organization Name and Address Department of Civil Engineering Engineering Experiment Station University of Illinois at Urbana-Champaign Urbana, Illinois 61801	10. Work Unit No. 11. Contract or Grant No. IHR-64
12. Sponsoring Agency Name and Address Illinois Department of Transportation 2300 South 31st Street Springfield, Illinois 62764	13. Type of Report and Period Covered Final Period Covered - to date 14. Sponsoring Agency Code

15. Supplementary Notes

Study was conducted in cooperation with the U. S. Department of Transportation, Federal Highway Administration

16. Abstract

A library system has been developed for the acquisition, compilation and storage of information relating to the fatigue behavior of metal members and structures. Test data obtained from the various information sources are stored on both data sheets (for individual examination), and on standard computer punch cards. A computer program has been developed to sort the data into sets satisfying certain stipulated specimen types and loading conditions. A "best-fit" S-N curve for each specified data set is then established using a least squares error of estimate and correlation coefficient of the regression line, and the lower tolerance limits for 99 percent survival at 50 percent and 95 percent confidence levels. The data and S-N curve are visually displayed using a CALCOMP plotter printout.

Information obtained from an analysis of the data in the Fatigue Data Bank for several selected details indicates that the current AASHO bridge design specification provisions, for these details, do not provide consistent correlations nor properly model the fatigue behavior of the details as established by laboratory tests.

17. Key Words	18. Distribution Statement
Fatigue, welded joints, metals, members, specifications, Computer analysis, data bank, S-N curves, reliability analysis.	

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	152	

Form DOT F 1700.7 (8-69)

ABSTRACT

A library system has been developed for the acquisition, compilation and storage of information relating to the fatigue behavior of metal members and structures. Test data obtained from the various information sources are stored on both data sheets (for individual examination), and on standard computer punch cards. A computer program has been developed to sort the data into sets satisfying certain stipulated specimen types and loading conditions. A "best-fit" S-N curve for each specified data set is then established using a least squares regression analysis. The output information includes the equation, the standard error of estimate and correlation coefficient of the regression line, and the lower tolerance limits for 99 percent survival at 50 percent and 95 percent confidence levels. The data and S-N curve are visually displayed using a CALCOMP plotter printout.

Information obtained from an analysis of the data in the Fatigue Data Bank for several selected details indicates that the current AASHO bridge design specification provisions, for these details, do not provide consistent correlations nor properly model the fatigue behavior of the details as established by laboratory tests.

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I. INTRODUCTION

1.1 Object and Scope

Extensive research on metal fatigue has been carried out and is continuing both in the United States and throughout the world. In a single investigation, the number of variables included for study is usually limited by the high cost of fabrication and testing of laboratory specimens. However, in order to establish and adequately quantify the relative influence of the various parameters that affect the fatigue behavior of structural materials, members and assemblages, it is necessary to have available the data from a large sampling of laboratory tests. One method of accumulating the bulk information necessary to obtain statistically significant fatigue evaluations is to compile and combine the data reported in the literature from numerous individual investigations. Once these data have been accumulated, computer-aided analytical techniques can effectively be used to empirically interrelate the variables found to be most important to the fatigue process.

The overall objectives of a system such as that outlined above are to make available to those persons responsible for design specifications, to structural designers, and to persons associated with research in this field, both the means for efficiently evaluating currently available fatigue information, and the capability of quickly processing new data for inclusion in the information bank. It is toward these ends that the program described herein has been directed.

1.2 Description of Program

As indicated above, the task of handling the large volume of data required to analyze the relative effects of the variables that affect the fatigue process must by necessity be relegated to an extensive information retrieval system. The generation of useful information rests on the ability of the system to rapidly retrieve, organize and process the data in a form suitable for efficient computer analysis. In terms of operational requirements, this requires both an expeditious procedure for the collection of fatigue references, and a thorough and reliable data reduction process to minimize bias in the recording and analysis of the data. Furthermore, the retrieval process of the system must provide the necessary channels for evaluating data by organizing such data in a form which facilitates the application of the analytical techniques developed to meet the program objectives. This feature requires a coherence between the form of the summarized data and the facilities (computer-oriented) available for data analysis. In schematic form an information-retrieval system of this type is illustrated in Fig. 1.1.

The information-retrieval system designed to assist in achieving the objectives of this program is the Fatigue Library System described in Section II. It has three modes of indexing bibliographic data (see Fig. 1.2a): author, information source, and bibliography number. Each of these provides a file which is cross-linked to at least one other file, as shown in Fig. 1.2c. In addition, duplicate information appears in several files, so that it is possible to retrieve desired information in a number of ways. Figure 1.2b indicates the type of information stored in each of the three indexing files and in the data file. From Fig. 1.2a, it can be seen that individual data sheets can be located in four ways: by author, source, bibliography number, and, through the data file itself by the type of test specimen. Although other retrieval operations are possible through the linkage of indexes, the system is primarily designed to retrieve fatigue test data.

Besides indexing bibliographic information, the system also includes an extensive classification procedure which contains thirty-three (33) categories for indexing test data for subsequent computer analysis. The computer program, described in detail in Section III, provides the means of obtaining statistical evaluations of the relative effects of individual parameters on fatigue; the parametric relationships thus obtained, taken collectively, should provide the information necessary for the generation of new or revised fatigue design requirements. The principal output from the computer program is in the form of standard S-N curves, complete with test points, and the standard error of estimate and lower tolerance limits for various survival percentages. In addition, the printed results include a listing of the input requirements, the data satisfying these requirements, and duplication of the output information displayed on the S-N diagrams.

1.3 Acknowledgments

This study was phase one of an investigation carried out as a part of the Illinois Cooperative Highway Research Program, Project IHR-64, "Welded Highway Structures," a cooperative effort between the Civil Engineering Department of the Engineering Experiment Station at the University of Illinois; the Illinois Division of Highways; and the U.S. Department of Transportation, Federal Highway Administration. The investigation is a part of the structural research program of the Department of Civil Engineering at the University of Illinois, under the general direction of Dr. N. M. Newmark, Professor and Head of the Department of Civil Engineering. It is administered by the University of Illinois Engineering Experiment Station of which Professor Ross J. Martin is Director, in the College of Engineering of which Dr. D. C. Drucker is the Dean.

The study described herein was conducted under the direction of W. H. Munse, Professor of Civil Engineering. The report has been prepared by Dr. J. B. Radziminski, Assistant Professor of Civil Engineering, and Messrs. R. Srinivasan, D. Moore and C. L. Thrasher, Research Assistants in Civil Engineering; however, the development of the system, the library searches, the recording of data and many other phases of the investigation have been carried out by a number of individuals while they served as Research Assistants in Civil Engineering at the University of Illinois. These included J. C. Cannon, M. R. Barone, T. M. Davis, H. Ottsen and V. K. Hariani as well as those previously noted.

The investigation was planned in cooperation with the IHR-64 Project Advisory Committee whose assistance and advice is gratefully acknowledged. The committee was composed of the following members:

Representing the Illinois Division of Highways:

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William J. Hall, Professor of Civil Engineering
John D. Haltiwanger, Professor of Civil Engineering

The opinions, findings, and conclusions expressed in this report are those of the authors and not necessarily those of the Illinois Division of Highways or of the Federal Highway Administration.

II. ACQUISITION, COMPILATION AND RETRIEVAL OF FATIGUE INFORMATION

2.1 General Description

The fatigue source filing system, described in detail in Section 2.2, provides the means by which literature concerning fatigue can be expeditiously compiled, catalogued, and filed for future reference. A diagrammatic representation of the interrelationships among the various components of the filing system is presented in Fig. 2.1.

Fatigue data from the literature included in the source library are extracted, classified, and recorded on appropriate data sheets using the procedures outlined in Section 2.3. In addition to direct storage of these sheets for future access, the data are coded and recorded on standard punch cards for computerized sorting and subsequent analysis; the coding system is discussed in Section 2.4.*

2.2 Compilation and Cataloguing of Fatigue Literature

It is intended that all accessible literature concerning fatigue be included in the fatigue library, irrespective of the inclusion or absence of actual "raw" fatigue data in a particular reference. Each such report is identified both by author (Author Index File) and by source (Source Reference List). In addition, if the report is found to contain usable

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* User's Manuals have been prepared as guidelines for the operation of the library system, including instructions on the preparation of fatigue data sheets, and the coding of these data for storage on computer punch cards.

data,* it is subsequently assigned a reference number (bibliography number) by which it is further identified in the filing system. Thus, the library consists basically of a source file, an author index file, and a chronologically ordered fatigue bibliography list (see Fig. 2.1) which are appropriately cross-referenced, Fig. 1.2, to facilitate retrieval of a particular document. A brief description of the contents of each of these files is presented below.

2.2.1 Source File

The Source File contains information on the literature related to fatigue; this information includes listings of documents which contain usable data, those searched but which contain no data, and those for which a data search has not been conducted. The latter group includes reports referenced in searched articles but which have not as yet been examined by the reviewers.

The Source File is comprised of Source Reference Lists, of which there are two general types--those for recording information from periodicals and those to be used for nonperiodical literature. There are five standard forms used for these lists, depending upon the type of source from which a

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* "Usable" fatigue data: data is compatible to the system if the fatigue tests conducted were of constant stress amplitude and if sufficient information has been reported so that stress vs. cycles to failure (S-N) diagrams can be generated. In addition, for the data to be properly recorded in the data file the test specimen must be clearly described for purposes of classification, and the base metal identified (base metal identification may, however, be quite general; e.g., "mild steel").

The system at the present time cannot accomodate fatigue data obtained from variable stress amplitude cycling such as programmed load-histogram cycling or random loading, nor can it accomodate data from strain controlled cycling unless the stress and strain were proportional throughout the test.

particular article or report has been taken (see Fig. 2.1 and descriptions below). For each Source Reference List or series of lists, there is a corresponding Source Information Sheet which provides instructions describing the procedure to be followed in completing the Source Reference List, together with other appropriate information concerning the particular periodical or report type.

The Source Reference List and companion Source Information Sheets are organized in the Source File in accordance with the index shown in Fig. 2.2. Within each category the lists are filed alphabetically by the name of the sponsoring agency (professional society, university, etc.). For sections in which a sponsoring agency designation does not apply (e.g., books, unpublished individual papers), the lists are filed alphabetically by the last name of the senior author. If a sponsoring agency for a publication is not known, the lists are temporarily placed in an unclassified source section until the sponsor is determined.

Details concerning the contents of the Source Information Sheets (Fig. 2.3) and Source Reference Lists (Fig. 2.4) are presented below.

As noted above, five standard forms (Figs. 2.4a-2.4e) are available to record bibliographic information, depending upon the type of source from which the information was obtained. Information for a periodical (a publication that has a volume number and an issue number and may or may not be published at regular intervals) is recorded on Form 1, 2, or 3, depending upon the publication interval of the source (Figs. 2.4a, 2.4b, or 2.4c). Instructions describing the format to be used in completing the Source Reference Lists for periodicals are given on the Source Information Sheet-Periodicals (Fig. 2.3a). An illustrative example of the method for com-

completing the Source Information Sheet-Periodicals and the Source Reference Lists is shown in Figs. 2.5a and 2.5b, respectively.

Bibliographic information on fatigue literature contained in a non-periodical such as a special report, thesis, book, bulletin, etc., is listed on either Form 4 or 5 (Figs. 2.4d and 2.4e). Form 4 is used when the non-periodical is sponsored by a specific group, such as a government agency, a university, etc., and is part of a series of reports issued at varying intervals, each with its own report number or other identifying designation. This form is used in conjunction with a Source Information Sheet-Nonperiodicals (Fig. 2.3b), which is to be completed in a manner similar to that used for periodicals. The report type, as required on Form 4, would include such entries as bulletins, technical reports, memoranda, etc.

Form 5 is used primarily for reports or papers given at conferences, and for books. These sources are issued only once and are not part of a series. They may be published by a sponsoring agency, however. The information given may include the author or authors, the title of the report, the date published, the publisher (if applicable), and the bibliography number if data is included.

2.2.2 Author Index File

An Author Index File (see Fig. 2.1) is maintained for all documents concerned with fatigue, regardless of whether the report contains usable data for subsequent analysis. This file thus serves as the major index to the entire fatigue library; as such, it is cross-referenced with the Source File and, where applicable, with the Fatigue Bibliography Number List and the fatigue data files (see Section 2.3).

A sample of a completed Author Index Card is shown in Fig. 2.6. The front of the card is completed as soon as it has been ascertained that a document is concerned with fatigue. Under "source," all information necessary for locating and identifying the source is recorded, including as appropriate, the source title, date, issue or report number, sponsoring agency, page numbers, etc. The source title should be identical to that used to identify and file the source in the Source File discussed previously. The local library call number or other location information should also be the same as that listed on the Source Information Sheet. If the report contains usable fatigue data, a bibliography number is assigned from the Fatigue Bibliography Number List (see Section 2.2.3) and recorded on the front of the index card.

The back of the Author Index Card is completed when the report is summarized. The information includes, in coded form, the specimen types tested (see Section 2.4 for specimen type classification and coding), the types of steel, and any additional information deemed important, such as cross referencing of bibliography numbers when data have been reported in more than one source. If a material other than steel has been tested, it should be identified on the card, using appropriate material specifications when available.

The index card is filed in the Author Index File alphabetically by the author's last name, and by the date of publication when several reports are listed for one author. In the event the report is presented by an agency, with no author(s) listed, the report is filed alphabetically by the name of the sponsoring agency.

Until a document is summarized (i.e., data extracted and placed on Fatigue Data Summary Sheets) the Author Index Card is filed in a "Non-Summarized" section of the Author Index File (see Fig. 2.1). When a report containing fatigue data has been summarized, its author card is then transferred to a "Summarized-Data" section of the file. If a report does not contain usable data, the card is filed in a "Summarized-No Data" section of the Author Index File.

2.2.3 Fatigue Bibliography Number List

A Fatigue Bibliography Number List is maintained which includes entries for all documents that have been found to contain usuable fatigue data. The bibliography number assigned to a report consists of the year in which the report was printed and the sequence in which it was reviewed among other reports printed in the same year. (A report will have more than one bibliography number if it was published in more than one source.) The sequence number is assigned when the report is entered in the Fatigue Bibliography Number List, an example of which is shown in Fig. 2.7. The list includes, for each report, the year of publication, the sequence number assigned, the author's name, and, after the information has been summarized (i.e., fatigue data extracted and recorded), a notation to that effect.

Once a bibliography number has been assigned to a document, this number is recorded both on the Author Index Card and in the appropriate space on the Source Reference List, as indicated previously. The document itself is then placed in a permanent Master File of Fatigue References for Steel Structures (see Fig. 2.1). Documents in this collection are filed by bibliography number.

2.2.4 Bibliography of Fatigue Data References for Steel Structures

As the fatigue library expands and additional fatigue data are added to the data bank, a Bibliography of Fatigue Data References for Steel Structures is to be maintained and updated periodically to include all new entries into the system. Part I of this list contains, in chronological arrangement, all the reviewed documents concerning fatigue of steel structures for which a bibliography number has been assigned. Each entry is listed, by bibliography number, using the standard reference format followed for published articles, books, etc., as illustrated in the sample shown in Fig. 2.8. Part II (see sample, Fig. 2.9) consists of an author index to all documents referenced in Part I.

2.3 Summarizing and Filing of Fatigue Data

All usable fatigue data (see definition, Section 2.2) are being summarized and maintained in a permanent Master Fatigue Data File. The process of summarizing data is accomplished by completing appropriate Fatigue Data Summary Sheets, two types of which are used, one for welded joints and assemblages, and the other for riveted and bolted joints and assemblages, Figs. 2.10a and 2.10b, respectively. The test results for plain specimens (e.g., plain plates and bars, rolled beam sections, etc.) are summarized on the form for welded specimens. A User's Manual has been prepared with complete instructions regarding the completion of the Fatigue Data Summary Sheets. Samples of completed sheets for several different types of test specimens are shown in Figs. 2.11a-2.11f..

After the data from a particular test or series of tests have been recorded on the appropriate data sheets, the sheets are filed in the Master Fatigue Data File. The filing is alphabetical by test specimen classification (see specimen category 10 in Section 2.4). The data sheets in each classification are then arranged in sequence by bibliography number.

2.4 Coding of Fatigue Data for Computer Analysis

In order to assemble and analyze, by computer, the fatigue data from various sources, it is necessary to record on computer punch cards the information summarized on the Fatigue Data Summary Sheets. The parameters selected for inclusion on the cards are:

1. Those necessary to describe the test specimen and testing environment, and
2. Those others considered to affect most markedly the fatigue behavior of the test members.

A total of thirty-three (33) parameters, coded to facilitate recording on the cards, have been established to characterize each fatigue test; the categories are listed in Fig. 2.12. The six-character code used to describe the type of test specimen (category 10, Fig. 2.12) on the computer cards is the same as that used to identify the specimen types on the Author Index Cards (see Fig. 2.6), and serves also as the descriptor by which the individual Fatigue Data Summary Sheets are filed.

The 33 fatigue data parameters listed in Fig. 2.12 are broadly classified under four divisions:

1. General Information
2. Material and Specimen Description
3. Specimen Fabrication Description
4. Test Conditions and Failure Description

Of the four divisions, (1), (2), and (4) are common to all specimen types, while division (3) has been further subdivided into two groups, one for welded specimens and one for riveted or bolted specimens. For the eight entries included in the first division, the actual numerical values (except category 3) are recorded in the appropriate FORTRAN format; the remaining parameters (categories 9 through 33) appear in coded form. The detailed description of the various parameters and their identifying codes are included in the User's Manual, which also contains the computer program developed to sort and analyze the data.

Since each of the 33 categories listed in Fig. 2.12 is essentially self-explanatory, it is necessary herein to expand only upon category 10, viz., "Description of Test Specimen." Each test specimen is identified by a six-digit descriptor, the coding of which is presented in Figs. 2.13a to 2.13f. The first letter or number (Fig. 2.13a) corresponds to a general description of the type of test specimen (plain material, welded joint, riveted or bolted joint, etc) and the type of loading applied to the specimen (whether axial, flexural, torsional, or some combination thereof). The second letter or number describes the overall configuration of the specimen, while the remaining digits describe the details of the connection, fasteners, etc. (see Figs. 2.13b to 2.13f for the detailed descriptions applicable to each of the general specimen types listed in

Fig. 2.13a). Examples of several types of typical fatigue test specimens and their corresponding coded descriptions are presented in Fig. 2.14 (see also data sheets for these specimen types, Figs. 2.11a through 2.11f).

The many specimen types included in Fig. 2.13 cover the vast majority of structural details tested to date under fatigue loading. However, if necessary, it would be a relatively simple matter to include other specimens not presently covered in the system by expanding as necessary one or more of the columns used as the specimen descriptors.

As noted above, the same six-digit code established to describe the test specimens for computer identification is used also to identify the specimen types on the Author Index Cards and on the individual Fatigue Data Summary Sheets. This facilitates the cross-referencing of the Author Index File with the Master Fatigue Data File and permits easy manual access to desired specimen data stored in the data file.

2.5 Information Retrieval

For the fatigue library system to fulfill its purpose, the information contained within the system must be readily accessible. As described below, the system is organized to permit the retrieval of fatigue data either manually or by means of a computer printout.

2.5.1 Manual Data Retrieval

The manual method of data retrieval is most efficient when the information desired is from a single report or a few reports. It is not suited to overall analysis or large withdrawals of information.

If the fatigue test specimen types reported in a particular reference are known, the data sheets may be obtained directly from the Master Fatigue Data File since, as described in Section 2.3, this file is indexed by test specimen classification. In addition, the data sheets for a particular report may be located if any one of the following items of information about the report is known: author's name, report source, or the bibliography number of the report. The data retrieval process using each of these items is outlined below.

If the author is known, the Author Index Card is located in the Author Index File; this card contains a list of the type(s) of specimens tested and the report bibliography number. With this information the data can be found in the Master Fatigue Data File.

If only the source of a particular report is known, the Source Reference Lists must be searched. When there is more than one report listed for the source, the search becomes a trial and error process. The author and bibliography number are given on the appropriate Source Reference List. Having the name of the author, the Author Index Card can be obtained to determine the test specimen types. It may be necessary to examine the data sheets from several reports before the correct one is found if more than one report is listed for a particular source.

If the bibliography number is known, the Master Bibliography Number List is entered directly to find the name of the author. Then, the Author Index Card can be obtained and the specimen types found as described above.

2.5.2 Computer-Aided Data Retrieval

It is in this function that the system is most useful and efficient. Rather than obtaining the data from specific reports, the system retrieves the data stored for each specified specimen type and test parameters, analyzes the data (i.e., establishes S-N curves, etc.), and prints both the original data and the analytical results in a directly usable format.

In most cases the user will be interested primarily in the influence of certain material or geometric parameters on the fatigue behavior of a specific type of specimen under one or various loading conditions. Section III contains a complete discussion of the computer program and the procedure for obtaining the desired information from the computerized system.

III. COMPUTER-AIDED ANALYSIS OF FATIGUE DATA

3.1 Introduction

As a result of the basically probabilistic nature of fatigue, and in recognition of the large number of diverse material, geometrical and environmental factors which affect the behavior of a structure when considered in its entirety, empirical fatigue analyses are commonly developed using data from tests of those specimens and models which, it is assumed, closely simulate the behavior of various components of the structure *in situ*. It must be recognized that the extrapolation of information, and the conclusions drawn from such analyses, are at best approximate. The justification for use of this approach, however, is threefold:

1. There is currently available a considerable amount of laboratory data for scaled structural members and details designed and tested for just this purpose;
2. Certain empirical relationships relating cyclic stress (or strain) to fatigue life have attained widespread acceptance in the engineering community as being relevant for a variety of materials, specimen details, loadings, and environmental conditions resulting in fatigue failures over several orders of magnitude of life; and
3. Design recommendations derived from such relationships are generally of sufficient simplicity as to be easily interpreted and applied by the design engineer.

Since design formulas based on empirical fatigue relationships obtained for complex structural details do not necessarily provide a fundamental understanding of the basic mechanisms involved in fatigue crack nucleation and propagation, the present level of technological advancement in this field still does not permit the extrapolation of data from a single type of small laboratory specimen to explain or predict (except in a qualitative way) the response of a complex system in which is embodied simultaneously several of the parameters considered critical to fatigue. Until such time as analytical tools are developed which can be applied to this problem with greater confidence, and recognizing the immediate need of the design engineer to have at his disposal recommendations for considering fatigue in design, the empirical approach pursued herein will continue to merit use.

As a result of many investigations with a variety of materials, it has been found that a curve of the type illustrated in Fig. 3.1 satisfactorily depicts the interrelationship between maximum applied stress,* for constant amplitude, stress controlled fatigue tests, and the resultant number of cycles to failure, where the two variables are plotted to logarithmic scales. The upper end of the "S-N" curve, representing lives normally from one-half cycle (static tensile test) to about 10^3 cycles to failure, is ill-defined since the nominal applied stresses are usually well above yield and plastic deformations (strains) predominate and control behavior. The S-N curve in this region has been found to be nearly horizontal for many materials, as might be expected;

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* Definitions of the terms used are presented in Appendix A.

small changes in controlled stress range reflect large increments in strain range and, therefore, result in large variations in fatigue life expectancy.

The central portion of the S-N curve illustrated in Fig. 3.1, representing the application of elastic cyclic stresses, may be reasonably approximated by a straight line on the logarithmic plot; it is this constant slope portion of the curve that has been used in the development of the fatigue formulas presented herein. For structural steels, the S-N curve then approaches a horizontal asymptote, usually somewhere between 10^6 and 10^7 cycles to failure; the corresponding cyclic stress is referred to as the fatigue limit, the cyclic stress below which the material would not be expected to fail in fatigue. For purposes of the present analysis, it is assumed that the long-life end of the fatigue spectrum may be approximated by the two linear curves illustrated by the dashed lines in Fig. 3.1. The point of intersection of the finite life S-N curve with the horizontal line is taken at 2×10^6 cycles to failure (except as noted in Appendix B).

3.2 Derivation of Fatigue Life Relationship

In order to develop the fatigue relationships used in the computerized analysis of available test data, it is first necessary to delineate the assumptions upon which the formulas are based. These assumptions, reflecting in part presently accepted postulates relating the response of a member or detail to the influence of constant amplitude stress cycling, are as follows:

1. A linear relationship exists, on a log-log basis, between the applied maximum cyclic stress (and, consequently, the

cyclic stress range) and the total number of cycles to failure. This linear regression line, Fig. 3.2, is taken to be valid for stresses below a state of "nominal" yielding over the member cross-section,* S_y (or S_p), at the low life end of the fatigue spectrum, and to fatigue lives to a maximum of approximately 2×10^6 cycles at the long life end.

2. For a specific material, specimen type, and testing environment, the linear log maximum stress-log life regression curves are applicable to tests conducted at all individual values of constant cyclic stress ratio, $R = S_{min}/S_{max}$, as shown in Fig. 3.2. (This linearity of log S_{max} vs. log N_f may be assumed valid, independently, for all values of cyclic mean stress or minimum stress instead of stress ratio. However, such assumptions are not mutually compatible, i.e., if it is determined that log S_{max} is linearly related to log N_f for all values of constant stress ratio, the corresponding log S_{max} (or log S_{range}) vs. log N_f regression lines for various values of constant mean stress or minimum stress will *not*, in general, be linear.)

From the above assumptions, it follows that the fatigue life expectancy of an individual specimen type may be described by the following exponential relationship:

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* For flexural tests, this state has been taken to correspond to an idealized condition of full yielding over the member cross section. See Appendix B for derivation of expressions for "nominal" flexural stress under this condition.

$$N_f = M_{a,b,c...} \cdot S_{max}^{B_{a,b,c...}}$$

or

$$\log N_f = A_{a,b,c...} + B_{a,b,c...} \cdot \log S_{max} \qquad (1)$$

where

$$A = \log M$$

The constants A and B (B is the inverse of the slope of the S-N curve*) are determined empirically from the experimental data for specimens tested at various constant stress ratios, R_a, R_b, R_c, etc., S_{max} is the maximum stress per cycle under constant amplitude loading, and N_f is the total number of cycles to failure.

3.3 Description of Computer Program for Analysis of Data

A computer program has been developed to perform the calculations necessary to generate the constants for the fatigue life relationship expressed by Equation 1. The program is written in FORTRAN IV language for use on the University of Illinois' IBM 360 computer system, with the S-N curves and specified tolerance limits being depicted graphically by a CALCOMP plotter. Details concerning the input data with which the computer operates, the expressions used to generate "best-fit" S-N curves, and the nature of the ouput information are presented in the following paragraphs.

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* For some specimen types, this slope has been found to be nearly constant for tests conducted at several stress ratios. The more general case is used here, however.

A flow diagram illustrating the various operations of the program is presented in Fig. 3.3.*

Initially, the computer program selects, from the complete bank of available test results, the data for specimens which satisfy desired combinations of specific member type(s), fabrication procedures and test conditions, referred to herein as prescribed parameters or data "sets". (As described in Section 2.4 and shown in Fig. 2.12, a total of thirty-three parameter categories are available to describe an individual fatigue specimen and test.) The program then generates and plots an S-N curve for the data whose test conditions match each set of prescribed parameters. By varying the composition of the specified data sets and comparing the resulting S-N curves, and fatigue relationships, the user can evaluate the relative effects on fatigue of various parameters, either individually or in combination with others.

After a desired parameter set has been prescribed, a "best fit" regression line is generated by applying the method of least squares[1] to the linear logarithmic fatigue life relationship expressed by Equation 1:

$$\log N_f = A + B \log S_{max}$$

For purposes of computation, Equation 1 has been expressed in the following manner:

$$x = A + By \qquad (2)$$

where $x = \log N_f$ and $y = \log S_{max}$ represent the transformed fatigue life

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* The complete computer program and operating instructions are contained in a separate User's Manual.

and cyclic maximum stress, respectively. Assuming this stress, S_{max}, to represent the independent variable and the fatigue life, N_f, to be the dependent variable, the constants A and B are established by the least squares regression analysis for a set of (n) fatigue data points as follows:

$$A = \frac{\Sigma x_i \; \Sigma(y_i)^2 - \Sigma y_i \; \Sigma (x_i \; y_i)}{n \; \Sigma(y_i)^2 - (\Sigma \; y_i)^2} \qquad (3)$$

$$B = \frac{n \; \Sigma \; (x_i \; y_i) - \Sigma \; x_i \; \Sigma \; y_i}{n \; \Sigma \; (y_i)^2 - (\Sigma \; y_i)^2} \qquad (4)$$

where all summations are from 1 to n.

It should be noted at this point that only data for tests conducted at maximum stresses below the "nominal" yield strength of the test member (see Appendix B) are included in the (n) data points. Similarly, a procedure has been developed to insure that data from "run-out" tests* are not indiscriminately included in the S-N curve computations. This procedure is presented also in Appendix B.

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* Run-out tests are those conducted with the intention of determining the fatigue limit for the test material or specimen. Basically, the cyclic stresses in successive tests are altered in a step-wise fashion until lives greater than 2×10^6 cycles are achieved without failure. Such tests are often not carried to complete failure, i.e., the tests are usually stopped somewhere beyond 2×10^6 cycles.

After the regression coeffients A and B have been determined by the method of least squares as outlined above, the standard error of estimate correlation coefficient, and the 50 percent and 95 percent confidence lower tolerance limits for 99 percent survival are computed. The determination of these quantities as used herein is based upon the following assumptions:

1. Fatigue life, N_f, is a random variable at each stress level examined.
2. The transformed fatigue lives, log N_f, follow a normal (Gaussian) distribution at each stress level* (i.e., the fatigue lives follow a "log-normal" distribution).
3. The standard error of estimate of the transformed fatigue lives is the same for all stress levels.

The correlation coefficient, r, represents an expression of the adequacy of the fit of the regression line to the observed fatigue data. If $r = \pm 1$, all pairs of x_i, y_i data points lie on the straight line expressed by Equation 2. As r deviates from the two limits, a decreasing adequacy of fit is indicated for the regression line. Basically, then, the correlation coefficient may be considered an indicator of how well a set of observed fatigue data can be described by the assumed exponential relationship, Equation 1.

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* Provision for use of other distribution functions, as for example, the widely accepted Weibull distribution,[2,3] can be accomplished with only minor changes to the present program if considered advisable at a later date.

The correlation coefficient, r, is computed as follows:

$$r = B \left[\frac{n \Sigma (y_i)^2 - (\Sigma y_i)^2}{n \Sigma (x_i)^2 - (\Sigma x_i)^2} \right]^{1/2} \quad (5)$$

where B is defined by Equation 4 and all summations again extend from 1 to n.

The standard error of estimate, s, expressive of the distribution of the data about the mean (best-fit) line for the assumed log-normal fatigue life distribution function, is determined by:

$$s^2 = \frac{\Sigma (x_i - \bar{x}_i)^2}{n - 2} \quad (6)$$

where x_i is the observed transformed fatigue life, log N_{f_i}, and $\bar{x}_i$ is the value of the transformed fatigue life estimated by the regression line, Equation 2, i.e.,

$$\bar{x}_i = A + By_i$$

Substituting the above expression into Equation 6, one obtains,

$$s^2 = \frac{\Sigma [x_i - (A + By_i)]^2}{n - 2} \quad (7)$$

By expanding the numerator and substituting Equation 3 for A in the above, the following expression is obtained, after appropriate re-arrangement of terms:

$$s^2 = \frac{[n \Sigma (x_i)^2 - (\Sigma x_i)^2] - B^2 [n \Sigma (y_i)^2 - (\Sigma y_i)^2]}{n (n - 2)} \quad (8)$$

or, the standard error of estimate, s, is equal to:

$$s = \left[\frac{[n \Sigma (x_i)^2 - (\Sigma x_i)^2] - B^2 [n \Sigma (y_i)^2 - (\Sigma y_i)^2]}{n (n - 2)} \right]^{1/2} \qquad (9)$$

Equation 9 is the form of the expression for the standard error of estimate as calculated by the computer.

The regression line established by Equation 1 represents the best estimate of the lives which 50 percent of the test specimens will survive and, consequently, the other 50 percent of the specimens will not attain. For purposes of design, it is usually required that curves for survivals well above 50 percent be determined as well. In the present program, the lower tolerance limits for 99 percent survival (at confidence levels of 50 percent and 95 percent) are computed.* The lower tolerance limit for a particular percent survival is of the form[1]:

$$x_{i_p} = \bar{x}_i - k(n, p, \gamma) \cdot s \qquad (10)$$

where, as above, $\bar{x}_i$ is the predicted transformed fatigue life and s is the standard error of estimate obtained from the regression analysis for a set of data containing n data points. The factor $k(n, p, \gamma)$ is a function of the number of points (n), the specified percent survival (p), and the confidence level (γ). The transformed fatigue life at the lower tolerance limit, x_{i_p}, corresponding to p percent survival for γ confidence, is then determined from Equation 10, where the function $k(n, p, \gamma)$ is obtained from the appropriate statistical tables for a normal distribution.[4,5] These tables have been included in the computer

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* Other survival limits can be computed if desired, by a straightforward modification of the computer program.

program, and the lower tolerance limits for 99 percent survival at 50 percent and 95 percent confidence are reported in the computer printout for each S-N curve, together with the correlation coefficient and the standard error of estimate (see Appendix C). The two lower tolerance lines are also displayed on the CALCOMP plot containing the S-N regression line and the data points.

The complete printed output, for each computed S-N curve, consists of the following:

1. A notation of the variable held constant in the generation of the log S_{max} (or log S_{range}) vs. log N_f regression line (i.e., whether the curve represents tests conducted at constant stress ratio, constant mean stress, or constant minimum stress).
2. A coded listing of the stipulated data parameter set for which the S-N curve was established.
3. A listing, including specimen number, cyclic maximum stress and fatigue life, of all specimens satisfying the specified test parameters.
4. A listing of the specimens rejected by the computer as having cyclic stress levels or fatigue lives beyond the limits permitted by the program for inclusion in the S-N curve computations (see Appendix B).
5. The constants A and B which define the equation of the best-fit S-N curve as established by the least squares regression analysis. Also, the correlation coefficient and standard error of estimate (see Appendix C).

6. A tabulation of the computed fatigue strengths at several selected fatigue lifetimes estimated by the best-fit regression line, together with the stresses corresponding to the standard error of estimate to either side of the regression line, and the stresses corresponding to the lower tolerance limit for 99 percent survival at 50 percent and 95 percent confidence, also computed at the same selected lifetimes (see Appendix C).

3.4 Program Flexibility

There is considerable flexibility incorporated in the program for the generation and display of the S-N regression lines. Specific examples include:

1. From one to five S-N curves, representing different specified parameter sets, can be plotted on one set of axes, permitting direct visual comparision of several curves.
2. Data satisfying one set of desired parameters can be combined in a single regression analysis with data satisfying up to four other specified parameter sets.
3. If a large scatter in certain fatigue data is anticicpated and no S-N curve is desired, points satisfying a desired parameter set may be plotted on the CALCOMP graph without computing and drawing an S-N curve through the points.
4. The program can generate and plot S-N curves relating either maximum stress or stress range to cycles to failure. These curves can be obtained for tests conducted at a constant

specified stress ratio, mean stress, minimum stress, or maximum stress (when the ordinate is stress range).

5. When a constant stress parameter (ratio, mean, minimum, or maximum) is specified for a desired parameter set, provision can be made for accepting only those data whose corresponding values of that stress parameter vary from the stipulated value by no more than a prescribed amount (e.g., tests conducted at a stress cycle of 1.0 ksi to 60.0 ksi could, if desired, be included in the analysis of specimens tested at a stress ratio of zero).

These are some of the variations that can be introduced into the program. However, because of the general manner in which the program has been developed, many other variations are possible also.

IV. ANALYSIS OF SAMPLE FATIGUE TEST DATA

4.1 Introduction

As stated in Section I, the major function of the system described herein is to provide for the rapid and efficient accumulation and statistical evaluation of fatigue test data. Such an evaluation will be of great value to researchers, structural designers, and to specification-writing agencies. The evaluative process provides for both the direct assessment of the fatigue behavior of structural materials and components, and of the relative effects of those design-oriented (member geometry, joining methods, etc.) and environmental parameters that influence the fatigue process. In addition, such evaluations can reveal those areas where data are currently inadequate or where the results indicate that some revision of current fatigue design philosophy or specifications is in order. This, in turn, will lead to specific recommendations for further fatigue research, thereby completing the full test-evaluate-modify-retest cycle.

In the following paragraphs, the operation of the fatigue analysis system is demonstrated by examination of the behavior of three types of fatigue test members: (a) plain plates, (b) full penetration butt weldments with reinforcement intact, and (c) full penetration butt weldments with reinforcement removed prior to testing. Comparisons are made among the members for specimens fabricated from each of three general classifications of steel: structural carbon steel; high-strength, low-alloy steel; and high yield strength quenched and tempered alloy steel. In those instances where large scatter in the fatigue test data for a specific member type precluded meaningful statistical analysis, an examination of the parameters contributing to the wide dispersion of fatigue lives is presented.

The results for each of the member types and steel categories are compared to the corresponding fatigue design requirements included in the current and tentative AASHO specifications.[7] It must be emphasized, however, that these comparisons are intended to be preliminary at this time, for the data upon which the computerized analyses are based represent only those tests currently in the fatigue library system. These data, although relatively complete, do not represent all of the appropriate data presently available in the literature, nor, of course, do they include information just becoming available at the time of preparation of this report. It should be noted, further, that the specimen categories of the AASHO specifications (A, D),[7] with which the results are compared, are used also for types of members other than the three considered herein. Nevertheless, certain observations from such comparisons are appropriate, insofar as they may be used to indicate when a gross disparity exists between test data and specification limitations which could be quite significant if the specifications are shown to be unconservative.

4.2 Results of Fatigue Data Analysis

4.2.1 Plain Plate Material

The plain plates considered in this study consist only of those tested in the "as-received" condition; i.e., full thickness plates containing the original plate surface with mill-scale intact. No specimens that were surface treated (e.g., descaled, polished, painted, galvanized, etc.)

have been included. For purposes of S-N curve formulation, the plates were grouped into three general classifications as follows:

	Classification	Steel Grades
1.	Structural Carbon Steel	A7, A36, A373, "mild steel"
2.	High-Strength, Low-Alloy Steel	A242, A441, A572
3.	High Yield Strength, Quenched and Tempered Alloy Steel	A514, A517

The results of the regression analysis for plain plates of each of the three steel classifications are presented in Tables 4.1, 4.2, and 4.3, and represented graphically in Figs. 4.1 through 4.3, and Figs. 4.9 through 4.11. The computed S-N curves and regression line constants from which the fatigue strengths reported in the tables were obtained are given in Appendix C, Plots 1 through 7.

Tables 4.1, 4.2, and 4.3 include the computed fatigue strengths at selected lifetimes of 10^5, 5×10^5, and 2×10^6 cycles corresponding to the regression lines for "best fit," and the lower tolerance limit for 99 percent survival at 50 percent confidence.* The results are reported for data from tests conducted at stress cycles of complete reversal, zero-to-tension, and, where available, for half-tension-to-tension. By means of simple linear interpolation, the fatigue strengths corresponding to other stress ratios can be approximated for fatigue lives of 10^5 and 2×10^6 cycles from the fatigue diagrams (modified Goodman) of Figs. 4.1, 4.2, and 4.3. (Only the computed fatigue strengths corresponding to the lower tolerance limit for

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* See discussion of regression analysis, Section 3.3.

99 percent survival at 50 percent confidence are included in the modified Goodman diagrams.)

An examination of the three grades of steel covered in Tables 4.1 through 4.3 reveals that, at short lives (10^5 cycles) there is a direct relationship between the fatigue strength ("best-fit curve") and the static tensile strength for stress cycles of both complete reversal and zero-to-tension. Further, as shown in the table below, the ratio of fatigue strength to tensile strength is approximately the same for all three grades and a given stress cycle (except for the quenched and tempered steel at zero-to-tension reflecting, perhaps, the lower tolerance of the material for the localized plastic deformations that are present in specimens for tests conducted near the material yield point).

		Complete Reversal		Zero-to-Tension	
Steel Grade	Static Tensile Strength (ksi)	Fatigue Strength $F_{100,000}$ (ksi)	Fatigue Strength / Tensile Strength	Fatigue Strength $F_{100,000}$ (ksi)	Fatigue Strength / Tensile Strength
Structural Carbon Steel	60	27	0.45	54	0.90
High-Strength Low-Alloy Steel	70*	37	0.53	64	0.91
High Yield Strength Quenched & Tempered Alloy Steel	115	62	0.54	90	0.78

* Median value used; range is from 60 ksi to 80 ksi.

At the long life end of the fatigue spectrum, there appears to be no consistent relationship between fatigue strength and static tensile strength. For example, at a fatigue life of 2×10^6 cycles, the fatigue strengths of the three grades of steel are within approximately 9 ksi of one another for a stress cycle of complete reversal, while at zero-to-tension the variation in fatigue strength is only about 6 ksi. Thus, at long fatigue lives corresponding to cyclic stresses well below the tensile strengths of the respective steel grades, the evidence indicates that a common fatigue strength (and, consequently, a common allowable stress for fatigue design) may be suitable to represent the entire range of steels examined herein, at least for stress cycles varying from complete reversal to zero-to-tension.

In Figs. 4.1 through 4.3. the fatigue test results from the plain plate material may be compared to AASHO design specifications[7] for lives of 10^5 cycles and 2×10^6 cycles. The comparisons can be made between the design curves and the computed fatigue strengths corresponding to the lower tolerance limit for 99 percent survival at 50 percent confidence. The design curves contain a cut off at a maximum stress corresponding to the static allowable stress values* but are shown also extrapolated linearly beyond the cut off point to provide a more meaningful comparison with test results.

The design relationships[7] for base metals (AASHO Category A) are:

a. For 100,000 cycles,

$$F_r = \frac{60}{1-R} \quad \text{but not more than } 0.55F_y \; . \; . \; . \; . \; . \; . \; . \qquad (11)$$

b. For 500,000 cycles,

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* The maximum allowable static stress corresponds to 0.55 x yield strength. For the high-strength low-alloy steels, a representative allowable static stress of 27 ksi, corresponding to a yield strength of 50 ksi, has been used.

$$F_r = \frac{36}{1-R} \quad \text{but not more than } 0.55F_y \quad \ldots\ldots\ldots \quad (12)$$

c. For 2,000,000 cycles,

$$F_r = \frac{24}{1-R} \quad \text{but not more than } 0.55F_y \quad \ldots\ldots\ldots \quad (13)$$

where

F_r = allowable fatigue stress, ksi (maximum stress)

R = Algebraic ratio of the minimum to the maximum stress

F_y = Minimum yield strength of the material

These correspond to constant ranges of stress of 60, 36, and 24 ksi for the three conditions shown.

If it is assumed that the fatigue resistance corresponding to the lower tolerance limit (LTL) for 99 percent survival at 50 percent confidence provides a suitable factor of safety for design (an assumption consistent with many fatigue specification requirements), a number of observations may be made concerning the present fatigue provision of the AASHO specifications[7] in relationship to the fatigue behavior of axially loaded plain plates. These are as follows:

a. Structural Carbon Steel (Figs. 4.1, 4.9. and Table 4.1)

For N_f = 100,000 cycles there is no fatigue design problem and only the basic maximum allowable stress ($0.55F_y$) need be considered. In fact, the LTL (lower tolerance level) in complete reversal is 20 percent above the allowable stress and for a zero-to-tension loading is

115 percent above the allowable stress. For N_f = 2,000,000 cycles the LTL in complete reversal is 48 percent above the allowable stress and for zero-to-tension is 27 percent above the allowable stress. However, if the fatigue relationship of Equation 13 is extended above the basic design stress limit (cut-off), the zero-to-tension ratio is 6 percent rather than 27 percent. Thus, it is evident that the current design relationships[7] do not provide a consistent correlation with the behavior of axially loaded plain plates.

b. High Strength Low Alloy Steel (Figs. 4.2, 4.10 and Table 4.2)

The low alloy steels, just as the structural carbon steels, are governed by the basic maximum allowable stress ($0.55F_y$). The ratios of LTL to the specified allowable stresses are:

	N_f = 100,000	N_f = 2,000,000
Complete Reversal	1.26	2.00
Zero-to-Tension	1.82	1.30

It is evident that the design relationships do not model properly the fatigue behavior of the axially loaded plain plates under the loading conditions represented by the data in Fig. 4.2.

c. High Strength Quenched and Tempered Alloy Steel (Figs. 4.3, 4.11 and Table 4.3)

The safety provided by the current fatigue design requirements[7] for the quenched and tempered steels is not as great as that noted above for the other structural steels. The ratios of the LTL to the specified allowable stresses are:

	N_f = 100,000	N_f = 2,000,000
Complete Reversal	1.22	1.03
Zero-to-Tension	1.10	0.98

Furthermore, the value of 1.03 would be 0.95 if the allowable were not limited by the basic maximum allowable stress ($0.55F_y$). In addition, it can be seen that the design relationships again do not model properly the fatigue behavior of the axially loaded plain plates under the loading conditions represented by the data in Fig. 4.3. (The slopes of the solid and dashed lines differ considerably.)

From the above discussion it is evident that the current AASHO fatigue design requirements[7] for base metal (Category A) do not provide good correlations with the behavior observed on the laboratory plain plates subjected to axial loads.

4.2.2 Transverse Butt Welds with Reinforcement Intact

Transverse butt welds with the reinforcement intact and fabricated in the three classifications of steel considered above (Section 4.2.1) have been included in this phase of the investigation. The results of the regression analyses, where possible, are presented in Tables 4.1, 4.2, and 4.3 and represented graphically in Figs. 4.4 through 4.6 and Figs. 4.9

through 4.11. The computed S-N curves and regression line constants from which the fatigue strengths reported in the tables were obtained, are given in Appendix C, Plots 8 through 14. The results are reported for data from tests conducted at stress cycles of complete reversal, zero-to-tension, and where available, for half-tension-to-tension. In the tables best fit, lower tolerance limit (99 percent survival and 50 percent confidence), and AASHO allowable[7] stress values are reported. (Only the computed fatigue strengths corresponding to the LTL and the AASHO allowables are included in the modified Goodman diagrams.)

An examination of fatigue resistance of the welded joints in terms of the static tensile strength of the base metal in the joints reveals a significant variation in magnitude. The ratios for the lower strength steels (structural and low-alloy) were 50 percent greater than those for the quenched and tempered steels, again reflecting the lower fatigue tolerance of the quenched and tempered steels; however, in this case, the relationships existed both at shorter lives (100,000 cycles) and at longer lives (2,000,000 cycles).

Of major importance in this analysis is the comparison of the fatigue resistance of the butt-welded joints with the AASHO allowable fatigue design stresses.[7] As in the case of plain plate material the comparisons are made between the design curves and the computed fatigue strengths corresponding to the lower tolerance limit (LTL) for 99 percent survival at 50 percent confidence, and for lives of 10^5 and 2×10^6 cycles. The AASHO design relationships[7] for weld metal or base metal adjacent to butt welds (Category D) are:

a. For 100,000 cycles (Structural Carbon Steel--A36)

$$F_r = \frac{20.5}{1-0.55R} \quad \text{but not more than } 0.55F_y \; . \; . \; . \; . \qquad (14)$$

b. For 500,000 cycles (Structural Carbon Steel--A36)

$$F_r = \frac{17.2}{1-0.62R} \quad \text{but not more than } 0.55F_y \; . \; . \; . \; . \qquad (15)$$

c. For 2,000,000 cycles (Structural Carbon Steel--A36)

$$F_r = \frac{15}{1-0.67R} \quad \text{but not more than } 0.55F_y \; . \; . \; . \qquad (16)$$

The allowable stresses obtained from these relationships are increased by as much as 63 percent for the quenched and tempered steel at 100,000 cycles, 22 percent at 500,000 cycles, and no increase at 2,000,000 cycles. The increases for the high-strength low-alloy steels are about 8 percent at 100,000 cycles, 3 percent at 500,000 cycles and no increase at 2,000,000 cycles. Comparisons of these fatigue design relationships[7] for butt welds with reinforcement intact, with the LTL for 99 percent survival at 50 percent confidence obtained from axially loaded transverse butt welds provide the following:

a. Structural Carbon Steel (Fig. 4.4, 4.9 and Table 4.1)

A large scatter, believed to be a result of variability in weld quality, was obtained under a complete reversal of stress (see Plot 8, Appendix C). Because of the degree of this scatter, S-N curves were not computed for the data and comparisons with the design relationships are difficult to make. Nevertheless, an examination of the data reveals that at a stress cycle of ±16.0 ksi lives ranging from 28,000 cycles to 1,634,300 cycles were obtained and these lives can be compared with an extrapolation from the design relationships of Equations 14, 15, and 16 of about 22,000 cycles. Thus, even with this tremendous variability in the data, the design relationships appear to provide adequate safety for complete reversal of stress.

For a zero-to-tension loading there also was a large amount of scatter but not of such magnitude as to preclude the calculation of an S-N curve. In this case it is found that for N_f = 100,000 cycles the LTL is well above the maximum allowable stress ($0.55F_y$). However, for 2,000,000 cycles the LTL is only 72 percent of the allowable stress and the average fatigue strength only 12 percent above the allowable stress. Thus, for long-life conditions the current design relationship appears to be unconservative and in need of adjustment.

b. High-Strength Low-Alloy Steel (Figs. 4.5, 4.10 and Table 4.2)

Because of a lack of data for axially loaded transverse butt welds in high-strength low-alloy steel subjected to a complete reversal of stress, S-N curves are not available and data cannot be plotted on the fatigue diagram of Fig. 4.5. Thus, a great need exists for information on the fatigue behavior of such members under reversal.

For the zero-to-tension loading, just as in the case of the structural carbon steel, there was a considerable scatter in the fatigue behavior. Nevertheless, an S-N curve has been computed and selected values are presented in Table 4.2 and Fig. 4.5. Again it can be seen that for N_f = 100,000 cycles the LTL is well above (40 percent) the maximum allowable stress. However, at 2,000,000 cycles the LTL is only 90 percent of the allowable stress, whereas the average fatigue strength is 38 percent above the allowable design stress. The long-life relationship would thus appear to be in need of revision.

A limited amount of data is available also for a loading of half-tension-to-tension. These data indicate that, for the half-tension-to-tension loading, a significant factor of safety exists even for N_f = 2,000,000. When combined with the zero-to-tension information, as shown in Fig. 4.5, it appears that the form of the basic design relationships may be in need of change also. However, such a change should be made with care.

c. High-Strength Quenched and Tempered Alloy Steel (Figs. 4.6, 4.11 and Table 4.3)

Extensive data are available for axially loaded transverse butt welds in the high-strength quenched and tempered alloy steels, thereby providing for an excellent comparison with the current design specifications.

The smallest amount of data is available for members subjected to a stress cycle of complete reversal. Nevertheless, the ratio of the fatigue resistance to the allowable stress appears to be satisfactory at both 100,000 and 2,000,000 cycles.

	N_f = 100,000	N_f = 2,000,000
Ratio of Average to Allowable[7]	1.59	1.51
Ratio of LTL to Allowable[7]	1.08	1.02

For a zero-to-tension loading, extensive data exists for the steels considered and S-N curves have been established. Again there is considerable scatter in the data, but this can be expected from the higher strength materials because of their fatigue sensitivity. In this instance the correlation with the specifications is not as good as for the case of reversal.

	N_f = 100,000	N_f = 2,000,000
Ratio of Average to Allowable[7]	1.62	1.43
Ratio of LTL to Allowable[7]	0.99	0.87

The allowable stress at 2,000,000 cycles appears to be somewhat high in this case.

Because of the high strength of the quenched and tempered steels, testing under half-tension-to-tension is possible, even to the shorter lives. Consequently, considerable data have been obtained under this type of loading cycle, and S-N curves established. When presented on the fatigue diagram of Fig. 4.6, it is readily evident that for this loading cycle the allowable stresses are overly conservative. Much more consistent design could be obtained from design relationships of the following type:

1. For 100,000 cycles (quenched and tempered steels)

$$F_r = \frac{33}{1-R} \quad \text{(for tensile loads only)} \; . \qquad (17)$$

$$(F_r)^{\pm} = \frac{33}{1-0.5R} \quad \text{(for cycles with reversal of stress)} \; . \; . \qquad (18)$$

but not more than $0.55F_y$.

2. For 500,000 cycles (quenched and tempered steels)

$$F_r = \frac{20}{1-R} \quad \text{(for tensile loads only)} \; . \qquad (19)$$

$$(F_r)^{\pm} = \frac{20}{1-0.5R} \quad \text{(for cycles with reversal of stress)} \; . \; . \qquad (20)$$

but not more than $0.55F_y$.

3. For 2,000,000 cycles (quenched and tempered steels)

$$F_r = \frac{13}{1-R} \quad \text{(for tensile loads only)} \; . \qquad (21)$$

$$(F_r)^{\pm} = \frac{13}{1-0.5R} \quad \text{(for cycles with reversal of stress)} \; . \; . \qquad (22)$$

but not more than $0.55F_y$.

The following tabulation provides a comparison of the results of the laboratory tests with the above relationships and shows a very consistent pattern of reliability or safety with the suggested design relationships.

Comparison of Fatigue Data with Allowable Stresses
Provided by Equations 17 to 22 Inclusive

Stress Cycle	Ratio of Average or LTL to Allowable	Ratio at Lives of, N_f = 100,000	N_f = 500,000	N_f = 2,000,000
Complete Reversal	ave/all.	1.56	1.57	1.56
	LTL/all.	1.01	1.06	1.06
Zero-to-Tension	ave/all.	1.65	1.65	1.65
	LTL/all.	1.00	1.00	1.00
Half-Tension-to-Tension	ave/all.	1.51	1.49	1.47
	LTL/all.	1.01	1.00	0.98

Just as in the case of plain plates, it is evident from the above discussion that the current AASHO fatigue design requirements for transverse butt welds[7] could be improved to provide a more consistent relationship to the fatigue behavior observed in the laboratory.

4.2.3 Transverse Butt Welds with Reinforcement Removed

The third type of member considered in this study is a full-penetration transverse butt weld for which the weld reinforcement has been removed and the surface ground in a direction parallel to the direction of loading to remove local transverse notches. A limited amount of data is available for this type of member. Nevertheless, where sufficient data exist, a regression analysis has been made and the resulting information is presented in Tables 4.1, 4.2, and 4.3 and in Figs. 4.7 through 4.11. The computed S-N curves and regression line constants from which the fatigue strengths reported in the tables were obtained are given in Appendix C, Plots 15 through 19.

Because of the limited data available the computed fatigue strengths are available only for a zero-to-tension loading cycle. However, an examination of Tables 4.1 and 4.2 indicates that in general the fatigue resistances of the members with the weld reinforcement removed is not greatly different than that of the members with the reinforcement intact. Thus, the benefits often reported for members with the reinforcement removed may not be a benefit that can be depended upon. Because of this the design specification for welds with the reinforcement removed may be less conservative than expected or possibly unconservative, particularily for welds with internal defects.

The AASHO design relationships[7] for butt welded splices for which the weld reinforcement has been removed are the same as for the base metal (see Equations 10, 11, and 12). Thus, higher allowable stresses are permitted when the weld reinforcement is removed. Comparisons of the allowable design stresses for butt welds with the reinforcement removed, with the LTL for 99 percent survival at 50 percent confidence obtained from axially loaded transverse butt welds provides the following:

a. Structural Carbon Steel (Figs. 4.7, 4.9 and Table 4.1)

Sufficient data are available only for an examination of a zero-to-tension loading, and even then the data are compromised by a large amount of scatter. Nevertheless, at 100,000 cycles, the LTL is well above the maximum allowable stress ($0.55F_y$). However, at 2,000,000 cycles, the maximum allowable stress is 58 percent above the LTL and only 8 percent below the average fatigue resistance. Thus, for long-life conditions the current design relationship appears to be unconservative and in need of adjustment.

The ratios of the fatigue resistance to the allowable stress are as follows:

	N_f = 100,000	N_f = 2,000,000
Ratio of Average to Allowable[7]	2.08	1.08
Ratio of LTL to Allowable[7]	1.21	0.63

b. High-Strength Low-Alloy Steel (Figs 4.8, 4.10 and Table 4.2)

As in the case of the structural carbon steel, a regression analysis was made only for a zero-to-tension loading, and then, only a limited amount of data was available. The relationship to the allowable design stress is also much lower than desired, indicating that for this type of steel the design relationships are also in need of adjustment.

The ratios of the fatigue resistance to the allowable stresses are as follows:

	N_f = 100,000	N_f = 2,000,000
Ratio of average to allowable[7]	1.31	1.21
Ratio of LTL to allowable[7]	0.79	0.72

c. High-Strength Quenched and Tempered Alloy Steel (Fig. 4.11 and Table 4.3)

Extensive data are available for the axially loaded transverse butt welds in the high-strength quenched and tempered alloy steels (see Plots 17, 18, and 19 of Appendix C). However, because of the large amount of scatter it was not possible to establish reasonable regression relationships from these data. In order to establish some measure of the validity of the AASHO design relationships the allowable stresses have been compared with the bottom of the scatter bands in Plots 17, 18, and 19 and provide the following:

Relation of Allowable to Bottom of Scatter Band*

Stress Cycle	N_f = 100,000	N_f = 500,000	N_f = 2,000,000
Complete Reversal	Below	Below	Below
Zero-to-Tension	Above	Above	Above
Half Tension-to-Tension	Below	Below	Below

* "Below" indicates that the design relationship is conservative and "above" indicates that it is unconservative, assuming that the allowable stress should not be above the bottom of the scatter band.

The above tabulation suggests that the current design provisions may be in need of adjustment for a zero-to-tension loading. However, if the several unusually low data points in Plot 18 are neglected (they appear to be extremely low), then all of the zero-to-tension values could be categorized "below" also and the specification would then appear to be very consistent. This matter, and the effect of weld defects on the behavior of these quenched and tempered members needs to be studied in more detail. Through the introduction of weld quality control it should be possible to obtain for these materials the same excellent correlations shown above for welds with the reinforcement intact and the design relationships of Equations 17 to 22 inclusive.

4.3 Discussion

It is readily evident from the discussions of the preceding sections that a data analysis system has been developed that can be used to provide an effective and important evaluation of the current AASHO design specifications.[7] It is also important to note that the system has been designed in such a manner that, as additional data become available, a re-analysis of all existing data or, if necessary, selected data can readily be made to update and improve design requirements.

Specifically, an analysis has been made of the fatigue behavior of (a) three types of members: plain plates, butt welds with the reinforcement intact, and butt welds with the reinforcement removed; (b) in three types of steel: structural carbon steel, low-alloy steel, and high-strength quenched and tempered steel; and (c) for various types of loading cycles: reversal, zero-to-tension, and half-tension-to-tension. In the analysis this behavior is compared in detail with the fatigue provisions of the current AASHO bridge design specifications.[7]

Based on the fatigue analyses it can be concluded that:

1. The current design relationships[7] for the three types of members studied do not provide consistent correlations nor properly model the fatigue behavior of the members established by laboratory tests.
2. In some instances the current design relationships are unconservative when related to the lower tolerance limit for 99 percent survival at a 50 percent confidence level of the available fatigue data.
3. The correlations with Equations 17 to 22 inclusive demonstrate the excellent reliability that can be established in design relationships when adequate laboratory data are available and a suitable number of design relationships are provided to cover both tensile loadings and loadings in reversal.

V. RECOMMENDATIONS

A fatigue analysis system has been developed and reported herein whereby large volumes of fatigue data can rapidly be retrieved, and statistically analyzed in terms of numerous interrelated parameters. In addition, the effectiveness of the system has been demonstrated by using the system to evaluate, for several types of members, the manner in which the current AASHO bridge design specifications[7] related to the existing data in the "Fatigue Data Bank." In view of the relatively poor correlations obtained in several instances between the design specifications and the laboratory data for the limited number of structural details studied, extensive additional evaluations are clearly needed. To make these evaluations and to make more effective use of the system described herein, the following steps are recommended.

1. To assemble and place in the Fatigue Data Bank all existing suitable fatigue data. Numerous new references are now available and provide data that should be added to the Fatigue Data Bank.
2. To analyze the available fatigue data for all types of structural members and details covered by the current bridge design specifications.
3. To evaluate the existing bridge design specifications in terms of the best available data, and to recommend modifications in these design requirements where necessary.
4. To define in detail those areas in which added fatigue data are required to better define the appropriate fatigue design relationships.

5. To initiate parametric studies of the many variables that affect the fatigue behavior of various types of members and connections in order that improvements in fatigue resistance might be realized through design and fabrication recommendations.
6. To expand the bibliographical data to include member descriptions in order that existing references for the many different types of members and details might be readily located by those possessing the Fatigue Data Bank bibliography.

The completion of these tasks will require a tremendous amount of time and effort. Nevertheless, the benefits that can be realized in terms of structural safety and reliability in structures that are subjected to repeated loads will be invaluable.

LIST OF REFERENCES

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2. American Society for Testing and Materials, "A Guide for Fatigue Testing and the Statistical Analysis of Fatigue Data," *ASTM Special Technical Publication No. 91-A*, Second Edition, ASTM, Philadelphia, Pa., 1963.

3. Wirsching, P. H. and Yao, J.T.P., "Statistical Methods in Structural Fatigue," *Journal of the Structural Division*, ASCE, Vol. 96, *No. ST6*, Proc. Paper 7377, June 1970, pp. 1201-19.

4. Owen, D. B., "Factors for One-Sided Tolerance Limits and for Variables Sampling Plans," *Sandia Corporation Monograph SCR-607*, Office of Technical Services, Dept. of Commerce, Washington, D. C., March 1963.

5. Natrella, M.G., "Experimental Statistics," *National Bureau of Standards Handbook 91*, U.S. Government Printing Office, Washington, D. C., 1963 (reprinted 1966).

6. Munse, W. H., *Fatigue of Welded Structures*, Welding Research Council, New York, N. Y., 1964.

7. American Association of State Highway Officials, *Standard Specifications for Highway Bridges*, Tenth Edition, 1969, with Interim Specifications, 1971.

TABLE 4.1

COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS
FOR STRUCTURAL CARBON STEEL

Specimen Type \ Stress Ratio	COMPLETE REVERSAL			ZERO TO TENSION			HALF TENSION TO TENSION		
	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**
FATIGUE STRENGTH AT 100,000 CYCLES (KSI)									
Plain Plate	26.5	24.1	(20.0)	54.0	42.9	(20.0)			(20.0)
Transverse Butt Weld with Reinforcement Intact			13.2	40.3	25.7	(20.0)			(20.0)
Transverse Butt Weld with Reinforcement Removed			(20.0)	41.7	24.3	(20.0)			(20.0)
FATIGUE STRENGTH AT 500,000 CYCLES (KSI)									
Plain Plate	22.4	20.4	18.0	40.9	32.5	(20.0)			(20.0)
Transverse Butt Weld with Reinforcement Intact			10.6	25.3	16.1	17.2			(20.0)
Transverse Butt Weld with Reinforcement Removed			13.8	27.8	16.2	(20.0)			(20.0)
FATIGUE STRENGTH AT 2,000,000 CYCLES (KSI)									
Plain Plate	19.4	17.7	12.0	32.1	25.5	(20.0)			(20.0)
Transverse Butt Weld with Reinforcement Intact			9.0	16.9	10.8	15.0			(20.0)
Transverse Butt Weld with Reinforcement Removed			9.0	19.6	11.4	18.0			(20.0)

* Lower Tolerance Limit

** Numbers in parentheses indicate maximum allowable stress based on static design considerations (0.55 x Yield Strength)

TABLE 4.2

COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS
FOR HIGH STRENGTH, LOW ALLOY STEEL

Stress Ratio / Specimen Type	COMPLETE REVERSAL			ZERO TO TENSION			HALF TENSION TO TENSION		
	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**
FATIGUE STRENGTH AT 100,000 CYCLES (KSI)									
Plain Plate	37.1	33.9	(27.0)	63.5	49.0	(27.0)			(27.0)
Transverse Butt Weld with Reinforcement Intact			15.0	49.8	32.5	23.2			(27.0)
Transverse Butt Weld with Reinforcement Removed			22.5	35.5	21.2	(27.0)			(27.0)
FATIGUE STRENGTH AT 500,000 CYCLES (KSI)									
Plain Plate	30.8	28.2	18.0	50.0	38.5	(27.0)			(27.0)
Transverse Butt Weld with Reinforcement Intact			11.1	31.1	20.3	18.0	69.3	52.0	26.1
Transverse Butt Weld with Reinforcement Removed			13.8	27.3	16.3	(27.0)			(27.0)
FATIGUE STRENGTH AT 2,000,000 CYCLES (KSI)									
Plain Plate	26.3	24.0	12.0	40.7	31.3	24.0			(27.0)
Transverse Butt Weld with Reinforcement Intact			9.0	20.7	13.5	15.0	42.0	31.6	22.4
Transverse Butt Weld with Reinforcement Removed			9.0	21.8	13.0	18.0			(27.0)

* Lower Tolerance Limit

** Numbers in parentheses indicate maximum allowable stress based on static design considerations (0.55 x Yield Strength)

TABLE 4.3

COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS
FOR HIGH YIELD STRENGTH, QUENCHED AND TEMPERED ALLOY STEEL

Specimen Type \ Stress Ratio	COMPLETE REVERSAL			ZERO TO TENSION			HALF TENSION TO TENSION		
	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**	Best Fit	L.T.L.* 99% Survival 50% Confidence	AASHO Allowable Stress**
FATIGUE STRENGTH AT 100,000 CYCLES (KSI)									
Plain Plate	62.0	36.7	30.0	90.2	56.8	(55.0)			(55.0)
Transverse Butt Weld with Reinforcement Intact	34.4	23.3	21.6	54.6	33.2	33.6	99.6	66.8	46.3
Transverse Butt Weld with Reinforcement Removed			22.5			45.0			(55.0)
FATIGUE STRENGTH AT 500,000 CYCLES (KSI)									
Plain Plate	36.0	21.3	18.0	56.2	35.4	36.0			(55.0)
Transverse Butt Weld with Reinforcement Intact	20.9	14.1	13.0	33.0	20.1	21.1	59.4	39.9	30.6
Transverse Butt Weld with Reinforcement Removed			13.8			27.5			55.0
FATIGUE STRENGTH AT 2,000,000 CYCLES (KSI)									
Plain Plate	22.5	13.3	12.0	37.4	23.5	24.0			48.0
Transverse Butt Weld with Reinforcement Intact	13.6	9.2	9.0	21.4	13.0	15.0	38.1	25.5	22.4
Transverse Butt Weld with Reinforcement Removed			9.0			18.0			36.0

* Lower Tolerance Limit

** Numbers in parentheses indicate maximum allowable stress based on static design considerations (0.55 x Yield Strength)

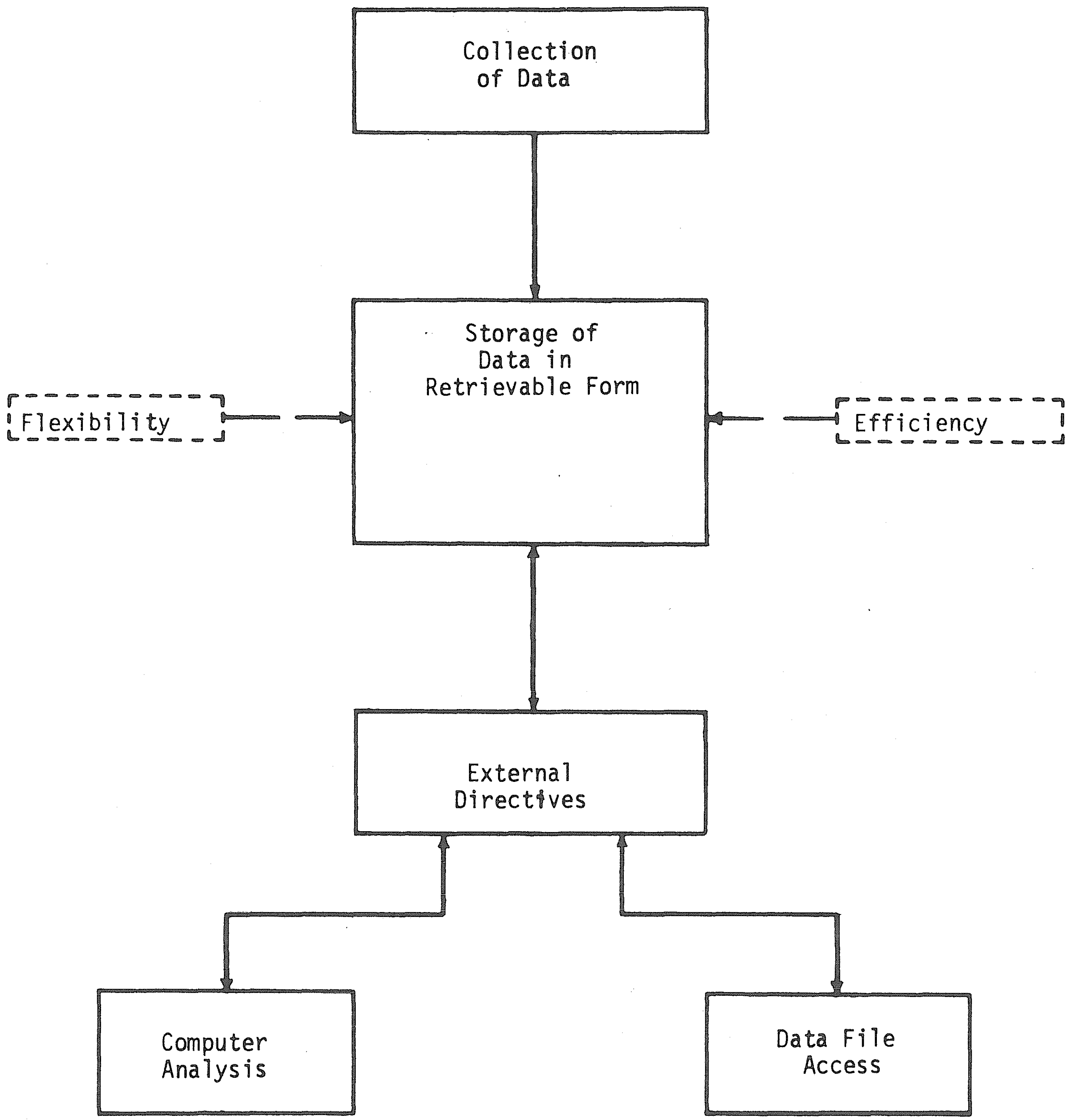
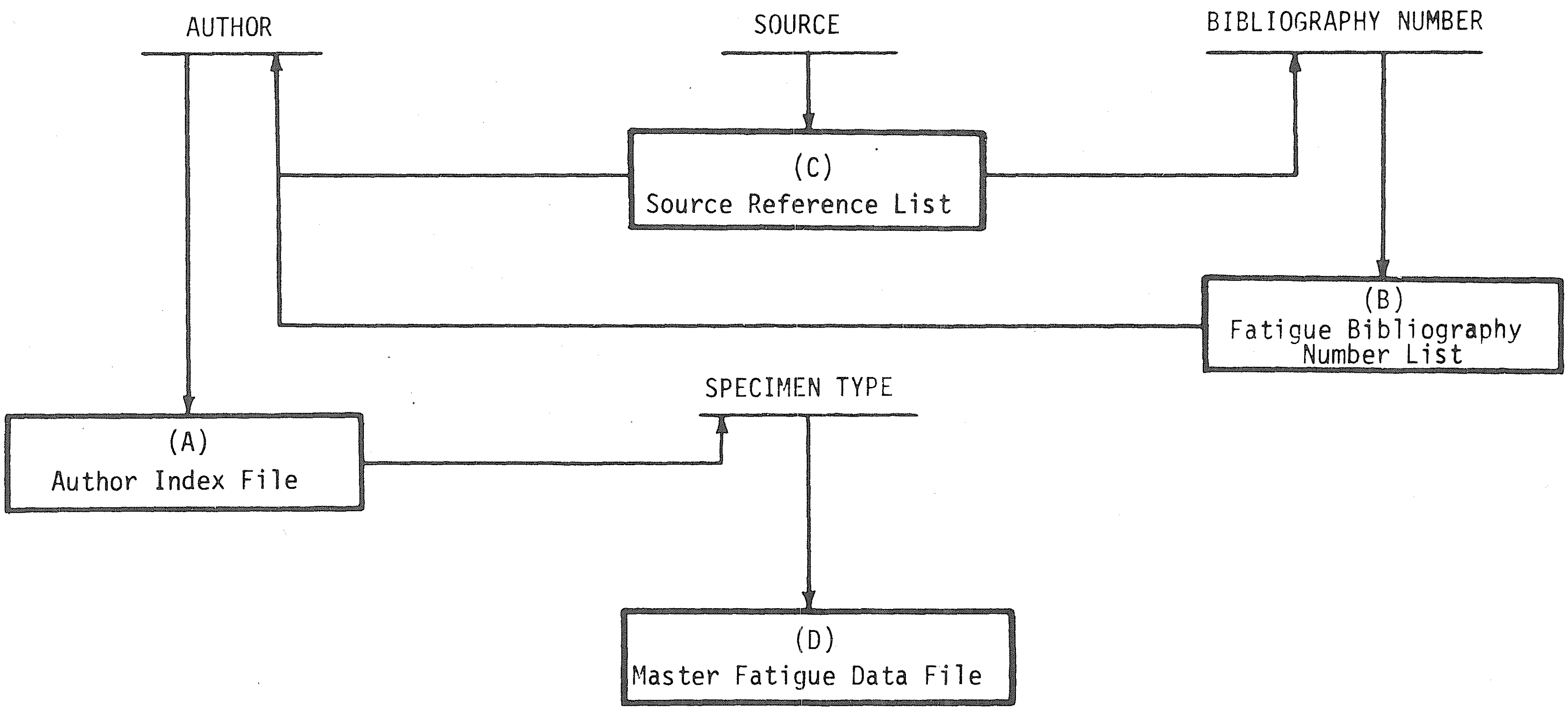


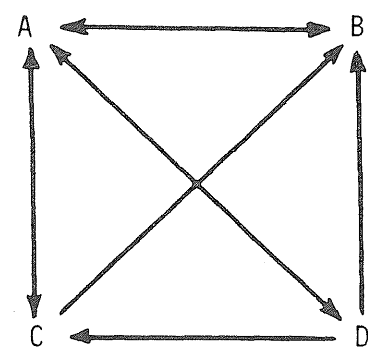
FIG. I.I DATA PROCESSING AND OUTPUT FUNCTIONS



Access to Data Sheets
(a)

Item	Located in File
Author	A B C D
Title	A - - D
Source	A - C D
Biblio. No.	A B C D
Specimen Type	A - - D
Steel Type	A - - D

Index Information
(b)



Linkage of Indexes
(c)

FIG. 1.2 SCHEMATIC OF THE FATIGUE LIBRARY SYSTEM

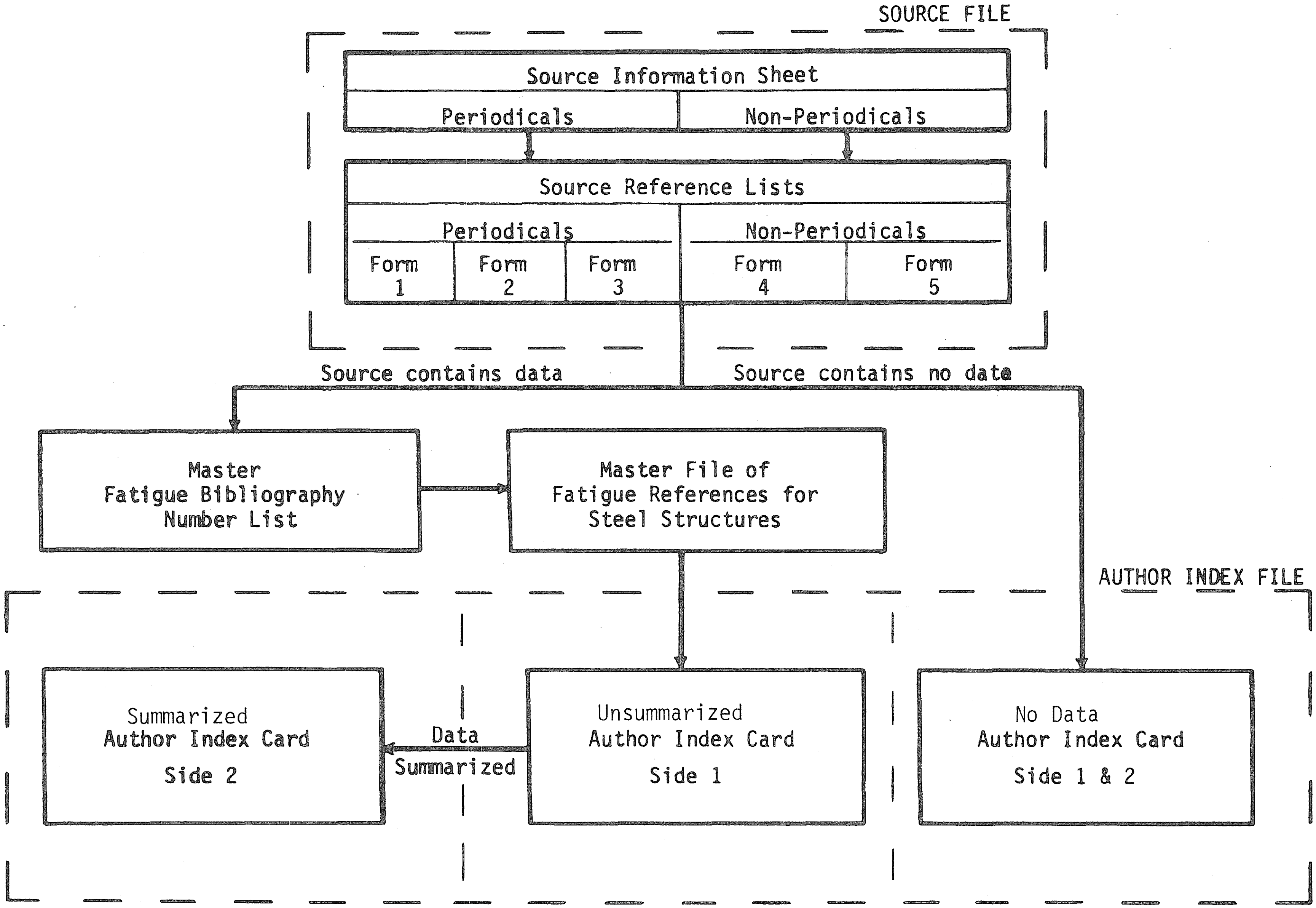


FIG. 2.1 FATIGUE INFORMATION SOURCE FILING SYSTEM

FILE SECTION	SOURCE CATEGORY
I	Government Agency Publications United States Foreign
II	Professional Society Publications National United States Foreign International
III	Private Research Organization Publications United States Foreign
IV	Educational Institution Publications United States Foreign
V	Corporation Publications United States Foreign
VI	Trade Publications United States Foreign
VII	Conferences International National
VIII	Books (Private Publishing Houses) United States Foreign
IX	Individual Papers United States Foreign
X	Unclassified Sources

FIG. 2.2 INDEX FOR SOURCE FILE

SOURCE INFORMATION SHEET
PERIODICALS

Source:

1. Instructions for filling out Source Reference List:
   a. Select appropriate Source Reference List Form (based on issue interval):
      weekly (Form 1) monthly (Form 2) quarterly (Form 3)
      other (specify and use Form 1,2, or 3)
   b. Record progress of search
      1. Record the year for which a search is being conducted.
      2. Place an x in the appropriate column (month, week, etc.) to record the completion of a search
   c. Record bibliographic information in author column
      1. On Form 1: record author-week, month (issue number), page (bibl. no.)
      2. On Form 2: record author-month (issue number), page, (bibl. no.)
      3. On Form 3: record author- (issue number), page (bibl. no.)

2. Library call no.:

3. Facilities for location of source:

4. Frequency of fatigue information:
   periodic frequent occasional seldom

5. Remarks:

FIG. 2.3a SOURCE INFORMATION SHEET FOR PERIODICALS

SOURCE INFORMATION SHEET
NON-PERIODICALS

Source:

1. Reports on Source Reference List (Form 4) are arranged by: (select one)

Chronological order   Series Number   Other (specify)

2. Library call no.:

3. Facilities for location of source:

4. Frequency of fatigue information:

periodic   frequent   occassional   seldom

5. Remarks:

FIG. 2.3b SOURCE INFORMATION SHEET FOR NON-PERIODICALS

SOURCE REFERENCE LIST (FORM 1)
(Weekly Periodical)

Yr					Weeks										AUTHOR
	1	2	3	4/5		1	2	3	4/5		1	2	3	4/5	
Ja					My					Se					
Fe					Ju					Oc					
Ma					Jy					No					
Ap					Au					Dc					
Yr															
Ja					My					Se					
Fe					Ju					Oc					
Ma					Jy					No					
Ap					Au					Dc					
Yr															
Ja					My					Se					
Fe					Ju					Oc					
Ma					Jy					No					
Ap					Au					Dc					
Yr															
Ja					My					Se					
Fe					Ju					Oc					
Ma					Jy					No					
Ap					Au					Dc					
Yr															
Ja					My					Se					
Fe					Ju					Oc					
Ma					Jy					No					
Ap					Au					Dc					

Source:

FIG. 2.4a SOURCE REFERENCE LIST, FORM I

SOURCE REFERENCE LIST (FORM 2)
(Monthly Periodical)

Yr	Ja	Fe	Ma	Ap	My	Ju	AUTHOR
	Jy	Au	Se	Oc	No	De	

Source:

FIG. 2.4b SOURCE REFERENCE LIST, FORM 2

SOURCE REFERENCE LIST (FORM 3)
(Quarterly Periodical)

Yr	1	2	3	4	AUTHOR

Source: ______________________________

FIG. 2.4c SOURCE REFERENCE LIST, FORM 3

SOURCE REFERENCE LIST (FORM 4)
(Non-Periodical)

Yr	Mo	Day	AUTHOR	REPORT TYPE	REPORT NO.	BIBL NO.	Yr	Mo	Day	AUTHOR	REPORT TYPE	REPORT NO.	BIBL NO

Source:

FIG. 2.4d SOURCE REFERENCE LIST, FORM 4

SOURCE REFERENCE LIST (FORM 5)
(Non-Periodical)

BIBLIOGRAPHIC INFORMATION	BIBL. NO.

FIG. 2.4e SOURCE REFERENCE LIST, FORM 5

SOURCE INFORMATION SHEET
PERIODICALS

Source: WELDING JOURNAL - RESEARCH SUPPLEMENT

1. Instructions for filling out Source Reference List:

   a. Select appropriate Source Reference List Form (based on issue interval):
      weekly (Form 1) [monthly (Form 2)] quarterly (Form 3)
      other (specify and use Form 1,(2), or 3)

   b. Record progress of search
      1. Record the year for which a search is being conducted.
      2. Place an x in the appropriate column (month, week, etc.) to record the completion of a search

   c. Record bibliographic information in author column
      1. On Form 1: record author-week, month (issue number), page (bibl. no.)
      2. On Form 2: record author-month (issue number), page, (bibl. no.)
      3. On Form 3: record author- (issue number), page (bibl. no.)

2. Library call no.: 669.17306 AM

3. Facilities for location of source: Engineering Library
   Professor W. H. Munse

4. Frequency of fatigue information:
   [periodic] frequent occasional seldom

5. Remarks: Journal of the American Welding Society

FIG. 2.5a SAMPLE OF COMPLETED SOURCE INFORMATION SHEET FOR PERIODICALS

SOURCE REFERENCE LIST (FORM 2)
(Monthly Periodical)

Yr 19	Ja Jy	Fe Au	Ma Se	Ap Oc	My No	Ju De	AUTHOR
60	X	X	X	X	X	X	Munse - Ap (4) 172s (N/D):
	X	X	X	X	X	X	
61	X	X	X	X	X	X	Sanders - De (12) 529s (61-1):
	X	X	X	X	X	X	
62	X	X	X	X	X	X	Fall - Ap (4) 145s (62-9): Kalbfleisch - Ja (1) 23s (62-13): Welter - Au (8) 368s (62-17):
	X	X	X	X	X	X	Yac - Ap (4) 182s (N/D): Kooistra - Jy (7) 297s (N/D):
63	X	X	X	X	X	X	Rolfe - Ju (6) 252s (N/D): Welter - De (12) 565s (63-20): Yen - Ju (6) 261s (N/D):
	X	X	X	X	X	X	Mindlin - Ju (6) 276s (63-32)
64	X	X	X	X	X	X	Berman - Jan (1) 24s (64-24): Manson - Au (8) 344s (N/D):
	X	X	X	X	X	X	
65	X	X	X	X	X	X	De Paul - Se (9) 409s (N/D): Reemsnyder - Oc (10) 458s (65-11): Freytag - Ap (4) 145s (N/D):
	X	X	X	X	X	X	Rolfe - Ja (1) 40s (65-2): Sanders - Fe (2) 49s (65-37): Wu - Au (8) 365s (65-33):
66	X	X	X	X	X	X	Payvar - Ap (4) 161s (66-29): Wood - Fe (2) 90s (N/D): Yeniscavich - Ma (3) 111s (N/D):
	X	X	X	X	X	X	
67	X	X	X	X	X	X	Crooker - Jy (7) 322s (N/D): Kaltenhauser - Se (9) 391s (67-20): Welter - Ja (1) 39s (67-5):
	X	X	X	X	X	X	Nippes - Ag (8) 371s (N/D):
68	X	X	X	X	X	X	Hickerson - Fe (2) 63s (N/D):
	X	X	X	X	X	X	
69	X	X	X	X	X	X	Hersh - Se (9) 389s (N/D): Howes - De (12) 543s (N/D): Reemsnyder - Ma (5) 213s (69-12):
	X	X	X	X	X	X	Toprac - Ma (5) 195s (69-11): Lindh - Fe (2) 45s (69-31):

Source: Welding Journal - Research Supplement

FIG. 2.5b SAMPLE OF COMPLETED SOURCE REFERENCE LIST FOR MONTHLY PERIODICAL

AUTHOR Sanders, W. W.; Derecho, A. T.; Munse, W. H.

TITLE Effects of External Geometry on Fatigue Behavior of Welded Joints

SOURCE Welding Journal--Research Supplement
Vol. 30, No. 2, February 1965 p. 49s
American Welding Society

LIB. CALL NO. 669.17306 AM
Prof. Munse BIBL. NO. 65-7

Front (side 1)

SPEC. TYPES AAFKBI AADXBI

STEEL ASTM A36-61T

ADDITIONAL INFORMATION
See also Bibliography Numbers 65-37 & 65-38

References to be checked--Done

Back (side 2)

FIG. 2.6 SAMPLE AUTHOR INDEX CARD

FATIGUE BIBLIOGRAPHY NUMBER LIST

Year 1965

Ref. No.	Author	*Summarized
1.+	Harrison, J. D.	Yes
2.+	Rolfe, S. T.; Haak, R. P.; Gross, J. H.	Yes
3.+	Kampschaefer, G. E., Jr.; Havens, F. E.; Bruner	Yes
4.+	Macfarlane, D. S.; Harrison, J. D.	Yes
5.+	Payvar, K.; Vasarhelyi, D. D.	Yes
6.+	Munse, W. H.; Stallmeyer, J. E., & Rone, J. W.	Yes
7.+	Sanders, W. W.; Dorecho, A. T. & Munse, W. H.	Yes
8.+	Toprac, A. A.	Yes
9.+	Selby, K. A.; Stallmeyer, J. E. & Munse, W. H.	Yes
10.+	King, D. C.; Slutter, R. G.; Driscoll, G. C., Jr.	Yes
11.+	Reemsnyder, H. S.	Yes
12.+	Braithwaite, A.B.M.	Yes
13.+	Harrison, J. D.	Yes
14.	Marsh, K. J.	Yes
15.+	Newman, R. P.; Dawes, M. G.	Yes
16.+	Harrison, F. D.	Yes
17.+	U. S. Navy, NASL, T. M. #31	Yes
18.+	U. S. Navy, NASL, T. M. #34	Yes
19.+	U. S. Navy, NASL, T. M. #39	Yes
20.+	Györgyi, F.	Yes
21.+	Walls, J. C.; Sanders, W. W.; Munse W. H.	

* Code: Yes--report has been summarized

\+ References available in File

FIG. 2.7 SAMPLE FATIGUE BIBLIOGRAPHY NUMBER LIST-ENTRY FORM

1969 (continued)

69-11* Toprac, A. A. "Fatigue Strength of Hybrid Plate Girders," Welding Journal Research Supplement, Vol. 48, No. 5, May 1969, pp. 195s-202s.

69-12* Reemsnyder, H. S. "Some Significant Parameters in the Fatigue Properties of Weld Joints," Welding Journal Research Supplement, Vol. 48, No. 5, May 1969, pp. 213s-20s.

69-13* Gurney, T. R. "A Re-Analysis of Some Fatigue Test Results Obtained for Specimens with Longitudinal Non-Load-Carrying Fillet Welds," The Welding Institute, Report E19/1/69, January 1969.

69-14* Nord, E. (Larsson, B., Editor). "Effect of Hot Dip Galvanizing on Fatigue Strengths of Steel," Swedish State Power Board, International Lead-Zinc Research Organization, Inc., Private Communication to Professors Birkemoe and Munse, Laboratory Report 12/19/63, June 25, 1969.

69-15* Fromm, K. "Dynamic Strength of Welded High Tensile Steels," International Institute of Welding 1969 Annual Assembly Public Session, July 14, 1969.

69-16* Nakamura, H., Kuriyama, Y. and Yamazaki, Y. "Application of 80 kg/mm^2 Grade High Strength Steel to High Pressure Vessels," International Institute of Welding Annual Assembly 1969 Kyoto, Japan, Public Session, July 14, 1969.

69-17* International Institute of Welding, Commission XIII. "The Effect of Slag Inclusions on the Fatigue Strength of Machined Butt Welds," Commission XIII Working Group, "Welding in the World," Vol. 7, No. 4, 1969, pp. 212-38.

69-18* Klöppel, K., Seeger, T. and Nowak, B. "Experimentelle und Theoretische Untersuchungen Zum Schodigungsverhalten Danerbeanspnichter Geschweipter Krenzstope aus St 37," Veroffentlichung des Instituts fur Statik und Stahlbau der Technischen Hochschule Darmstadt, Heft 5, 1969.

69-19* Colson, G. and Massonnet, C. H. "Essais de Fatigue Plastique sur des Eprouveltes lisses et Entailles," Centre de Reserches Scientifiques et Techniques de l'industrie des Fabrications Metalliques (CRIF), MT 46, Belgium, March 1969.

69-20* Sperle, J. O. "Influence of Static Mean-Stress on the Fatigue Strength of Welded Joints," Unpublished work--Summary of results taken from Monograph on Fatigue Strength of Welds, Section II, issued by Svetskommissionen Ingeniorsvetenskapsakademien (Royal Swedish Academy of Engineering Sciences), Stockholm, 1969, pp. 041A-041-17.

FIG. 2.8 SAMPLE PAGE OF "FATIGUE DATA REFERENCES FOR STEEL STRUCTURES-PART I"

Sagalevich, V. M. 65-40
Sagawa, M. 70-15
Sahgal, R. K. 60-1, 63-1, 63-2
Saiga, Y. 71-11, 71-12, 71-42
Sakabe, K. 67-17
Salive, M. L. 64-32
Salkin, R. V. 70-33
Sanders, W. W., Jr. 57-6, 60-2, 61-1, 62-20, 65-7, 65-21, 65-22, 65-37, 65-38, 71-30
Sanderson, R. A. 69-3
Saruki, K. 68-7
Satoh, K. 69-29
Savel'ev, V. N. 60-19, 61-11, 65-34
Schick, W. 31-1, 33-1, 34-4
Schlegel, H. 59-9
Schmidt, W. 64-10
Schoenmaker, P. 36-1, 36-3
Schönrock, K. 37-4
Schulz, E. H. 32-6, 33-5, 52-2
Schutz, F. W. 50-3
Schwab, R. C. 65-44
Schwarz, H. 59-9
Schwenninger, D. 66-30
Scott, G. R. 61-20, 61-21, 63-3
Seeger, T. 64-22, 65-24, 69-18, 69-26, 70-6
Seferian, D. 46-4
Seki, M. 67-40,
Selby, K. A. 63-16, 63-31, 65-9
Serensen, S. V. 71-18, 71-19
Sherman, D. R. 62-6, 63-5, 63-6, 64-31
Shibata, T. 67-39
Shinozuka, M. 71-35
Shore, R. J. 70-70
Shoukry, Z. 56-1
Shuck, R. R. 63-8, 64-37
Signes, E. G. 67-10, 67-54, 68-26
Sijs, A. 69-33
Sines, G. 49-5, 51-7
Slutter, R. G. 65-10, 66-17
Smidth, F. L. and Co. 59-14
Smith, B. 66-24, 70-44
Smith, G. C. 64-4, 67-19, 67-48, 67-53
Smith, J. O. 39-8
Snyder, E. S. 50-1
Soete, W. 50-2, 52-1, 66-18, 66-20, 67-25, 68-9
Sonda, T. 70-59
Sperle, J. O. 69-20, 71-16
Spiers, R. 68-17
Srinivasan, R. 71-21, 71-22
Stallmeyer, J. E. 55-1, 55-10, 56-1, 56-4, 57-2, 57-13, 58-1, 58-2, 58-6, 59-1, 59-12, 60-5, 61-3, 61-4, 61-20, 61-21, 62-6, 62-8, 62-22, 63-1, 63-2, 63-3, 63-4, 63-5, 63-6, 63-16, 63-31, 63-37, 64-31, 65-6, 65-9, 66-4, 66-22, 67-13
Steffens, H. D. 59-16, 71-15
Steinhardt, O. 59-4, 65-25, 69-34
Steneroth, E. R. 68-5
Stephens, P. J. 71-36
Stern, I. 61-6, 62-16
Stöckman, G. 69-33
Stout, R. D. 65-31
Strating, J. 71-34
Sturm, D. 68-19, 70-18
Stussi, F. 49-4
Suhr, R. W. 70-42
Sumita, M. 70-11, 70-61
Sunamoto, D. 67-42
Swindlehurst, J. 59-2
Switek, W. 68-4

FIG. 2.9 SAMPLE PAGE OF "FATIGUE DATA REFERENCES FOR STEEL STRUCTURES - PART II"

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

WELDED SPECIMENS

Data Recorded on Fatigue Coding Form No. ________

BASE METAL PROPERTIES

(9) Specification Designation: ________

Manufacturing Process: ________

Shape or Plate Description: ________

MECHANICAL PROPERTIES (COUPON)

(4) Yield Point: ________

(5) Ultimate Strength: ________

Percent Red. of Area: ________

Percent Elong. in ____ Gage Length: ________

CHEMICAL COMPOSITION, Percent

C ____ Mn ____ P ____ S ____

Si ____ ____ ____ ____

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: ______ (12) Rep. Dimensions: ______

(16) Theoretical Stress Conc. Factor; K_t: ________

(17) Critical Stress Intensity Factor; K_c: ________

Fabrication, Spec., Notes, Remarks:

SPECIMEN PROPERTIES

Yield Point	Ultimate Str

AVE. FATIGUE STRENGTH

Stress Cycle: ________

Cycles	Stress
100,000	
2,000,000	

K: ________

Reviewer: ________ Ck'd: ________

Date: ________

Library Ref. No.: ________

TEST CONDITIONS

(25) Environment: ________

(26) Temperature: ________

(27) Loading Frequency: ________

(28) Type of Loading: ________

(10) SPECIMEN TYPE: ________

(1) BIBLIOGRAPHY NO.: ________ Sheet ____ of ____

Author(s): ________

Title: ________

Source: ________

Volume: ________ Number: ________

Date: ________ Pages: ________

These Data from Pages: ________

(3) Units for Test Data: ________

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	Stress Cycle (7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL

(29) Method of Load Measurement:

(30) Basis for Stress Calculation:

* Ratio, $\frac{\text{Crack Propagation Life}}{\text{Total Fatigue Life}}$

(31) Failure Criterion: ________

WELDING DESCRIPTION

(18) Welding Process: ________

(19) Welding Gas Used: ________ (19) Welding Position: ________

(19) Electrode Type and Handling Description: ________

(20) Weld Defect Description: ________

Pass No.	(19) Electrode Size and Spec.	(19) Amps A.C.-D.C.	Volts	Speed of Welding	Back Chip. or Grinding Yes or No	(19) Polarity:
						(24) Preheat Temperature:
						Interpass Temperature:

(21) N.D.T. Observations:

(22) Weld Inspection:

(23) Weld Repair History:

(13) & (14) Surface Treatment, Finish, Coating: ________

(15) Mechanical and/or Thermal Stress Alteration Treatment Before or After Welding: ________

FIG. 2.10a FATIGUE DATA SUMMARY SHEET FOR WELDED SPECIMENS

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

RIVETED AND BOLTED SPECIMENS

Data Recorded on Fatigue Coding Form No ______

BASE METAL PROPERTIES

(9) Specification Designation: ______
Manufacturing Process: ______
Shape or Plate Description: ______

MECHANICAL PROPERTIES (COUPON)

(4) Yield Point: ______
(5) Ultimate Strength: ______
Percent Red. of Area: ______
Percent Elong in ____ Gage Length: ______

CHEMICAL COMPOSITION, Percent

C ____ Mn ____ P ____ S ____
Si ____

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: ______ (12) Rep. Dimensions: ______
(24) Ratio, $\frac{\text{Net Area}}{\text{Gross Area}}$: ______

(16) Theoretical Stress Conc. Factor; K_t: ______
(17) Critical Stress Intensity Factor, K_c: ______
Fabrication, Spec., Notes, Remarks:

SPECIMEN PROPERTIES

Yield Point	Ultimate Str

AVE. FATIGUE STRENGTH

Stress Cycle: ______

Cycles	Stress
100,000	
2,000,000	

K: ______

Reviewer: ______ Ckd ______
Date: ______
Library Ref No.: ______

TEST CONDITIONS

(25) Environment: ______
(26) Temperature: ______
(27) Loading Frequency: ______
(28) Type of Loading: ______

(10) SPECIMEN TYPE: ______
(1) BIBLIOGRAPHY NO: ______ Sheet ____ of ____
Author(s): ______
Title: ______
Source: ______
Volume: ______ Number: ______
Date: ______ Pages: ______
These Data from Pages: ______

(3) Units for Test Data: ______

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	Stress Cycle (7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL*

(29) Method of Load Measurement:

(30) Basis for Stress Calculation:

* Ratio, $\frac{\text{Crack Propagation Life}}{\text{Total Fatigue Life}}$

(31) Failure Criterion: ______

FASTENERS

(19) Type: ______ (19) Specification & Country: ______ (19) Diameter: ______
Yield Strength: ______ (19) Ultimate Strength: ______ Elongation, %: ______ Hardness: ______
Chemical Comp.: C ____ Mn ____ P ____ S ____ Si ____ (10) Hole Clearance: ______
(20) Clamping Force: ______ (10) Hole Preparation: ______

RIVETS

(19) Head Type: ______
(20) Manufacture: Hot Formed ____ Cold Formed ____
(20) Driving: Hot ____ Cold ____
Manual ____ Machine ____
Other: ______

BOLTS

(19) Type: ______
(21) Type of Thread: ______ (22) Type of Nut: ______
(22) No. and Type of Washers: ______
(23) No. of Threads in Grip: ______
(20) Installation Procedure: ______

(13) & (14) Faying Surface Treatment, Cleaning, Finish and/or Coating: ______

(15) Mechanical and/or Thermal Treatment Before or After Fabrication: ______

FIG. 2.10b FATIGUE DATA SUMMARY SHEET FOR RIVETED AND BOLTED SPECIMENS

FATIGUE DATA SUMMARY - DEPARTMENT OF CIVIL ENGINEERING - UNIVERSITY OF ILLINOIS - URBANA, ILLINOIS

WELDED SPECIMENS

Data Recorded on Fatigue Coding Form No 0017

BASE METAL PROPERTIES

(9) Specification Designation: USS T-1 (ASTM A-514F)
Manufacturing Process:
HEAT No. 735578
Shape or Plate Description: 3/4" THK. X 9" WIDE X 48" LONG

MECHANICAL PROPERTIES (COUPON)

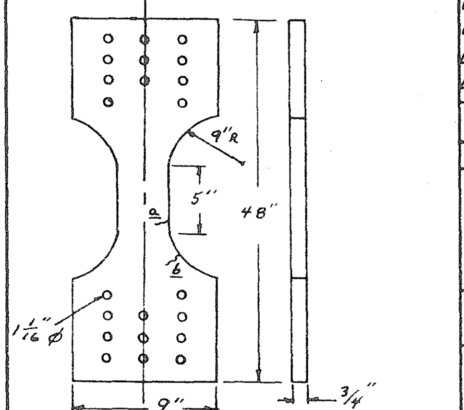
(4) Yield Point: 107.45
(5) Ultimate Strength: 116.15
Percent Red. of Area: not given
Percent Elong. in 2" Gage Length: 28.0

CHEMICAL COMPOSITION, Percent

C 0.17 Mn 0.71 P 0.012 S 0.020
Si 0.23 Ni 0.79 Cr 0.47 V 0.05
Mo 0.43 Cu 0.23 B 0.004

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: 3/4" (12) Rep. Dimensions: 4"



(16) Theoretical Stress Conc. Factor; K_t: not given
(17) Critical Stress Intensity Factor; K_c: not given
Fabrication, Spec., Notes, Remarks:

SPECIMEN PROPERTIES

Yield Point	Ultimate Str

AVE. FATIGUE STRENGTH
Stress Cycle: 0-T

Cycles	Stress
100,000	69.3
2,000,000	38.1

K: 0.200

Reviewer: A. Liu Ck'd: BGM
Date: NOVEMBER 11, 1966
Library Ref No.:

TEST CONDITIONS

(25) Environment: AIR
(26) Temperature: Room
(27) Loading Frequency: 100 or 180 cpm
(28) Type of Loading: AXIAL Concentric

(10) SPECIMEN TYPE: AAXXXL
(1) BIBLIOGRAPHY NO. 65-6 Sheet 1 of 9
Author(s): MUNSE, W. H., STALLMEYER, J. E., RONE, J. W.
Title: FATIGUE BEHAVIOR OF PLAIN PLATE AND BUTT-WELDED JOINTS IN T-1 STEEL
Source: UNIV. OF ILL. REPORT FOR U. S. STEEL CORPORATION
Volume: Number:
Date: JANUARY, 1965 Pages: 1-53
These Data from Pages: TABLES 1, 2, 4; FIG. 1a + 4a
(3) Units for Test Data: KIP - INCH - SEC. - °F

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	Stress Cycle (7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL
USP-1	0.0	+55.0	173,600	b Initiated in Transition Radius	not
USP-2	0.0	+57.4	318,600	Initiated in Test section at edge near Transition radius a	given
USP-3	0.0	+60.0	203,500		
USP-4	0.0	+40.0	1,234,400		
USP-5	0.0	+40.0	3,500,000	No FAILURE	
USP-6	0.0	+50.0	558,190	Initiated in Transition Radius	b
USP-7	0.0	+40.0	1,130,000	In Test section near Radius	a

\# Ratio, Crack Propagation Life / Total Fatigue Life

(31) Failure Criterion: EXCESSIVE DEFORMATION CAUSED A MICRO-SWITCH TO STOP MACHINE; CRACK USUALLY 1/2 THROUGH SPECIMEN

(29) Method of Load Measurement: LOAD ON SPECIMEN MEASURED BY MEANS OF A DYNAMOMETER ON THE FATIGUE MACHINE

(30) Basis for Stress Calculation: $f = \frac{P}{A}$ based on nominal plate dimensions

WELDING DESCRIPTION

(19) Welding Process: NOT APPLICABLE
(19) Welding Gas Used: (19) Welding Position:
(19) Electrode Type and Handling Description:
(20) Weld Defect Description:

Pass No.	(19) Electrode Size and Spec.	(19) Amps A.C.-DC.	Volts	Speed of Welding	Back Chip. or Grinding Yes or No

(19) Polarity:
(24) Preheat Temperature:
Interpass Temperature:

(21) N.D.T. Observations:
(22) Weld Inspection:
(23) Weld Repair History:

(13) & (14) Surface Treatment, Finish, Coating: AS ROLLED SURFACES EDGES MACHINED, DRAW FILED AND POLISHED

(15) Mechanical and/or Thermal Stress Alteration Treatment Before or After Welding: NONE - STEEL IS A HEAT TREATED STEEL

FIG. 2.11a SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET-AS-ROLLED PLAIN-PLATE

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

WELDED SPECIMENS

Data Recorded on Fatigue Coding Form No ______

BASE METAL PROPERTIES

(9) Specification Designation: HY-80
Manufacturing Process: not given
Shape or Plate Description: 2½" THICK

MECHANICAL PROPERTIES (COUPON)

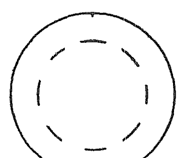
(4) Yield Point: 92.7
(5) Ultimate Strength: 104.8
Percent Red. of Area: not given
Percent Elong. in 2" Gage Length: 29.1

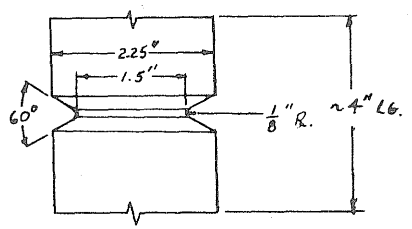
CHEMICAL COMPOSITION, Percent

C ____ Mn ____ P ____ S ____
Si ____

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: 1.5" (12) Rep. Dimensions: 1.5"





(16) Theoretical Stress Conc. Factor; K_t: 2.4
(17) Critical Stress Intensity Factor; K_c: NOT GIVEN

Fabrication, Spec., Notes, Remarks: SPECIMEN MACHINED FROM 2½" THICK STEEL PLATES. THE NOTCH WAS MACHINED. SPECIMEN WAS INSTRUMENTED TO DETERMINE STRAIN RANGE ALSO

SPECIMEN PROPERTIES

Yield Point	Ultimate Str.

AVE. FATIGUE STRENGTH

Stress Cycle: 0 → C

Cycles	Stress
100,000	
2,000,000	

K:

Reviewer: A. Liu Ck'd: DDm
Date: SEPT. 5, 1967
Library Ref No.:

TEST CONDITIONS

(25) Environment: AIR
(26) Temperature: Room
(27) Loading Frequency: 10-12 cpm
(28) Type of Loading: AXIAL - Concentric

(10) SPECIMEN TYPE: ADAAEI
(1) BIBLIOGRAPHY NO: 64-10 Sheet 1 of 3
Author(s): PICKETT, A.G.; SCHMIDT, W.R., WHITING, A.R.
Title: A STUDY OF LOW-CYCLE FATIGUE STRENGTH OF COMPRESSIVE SPECIMENS MADE OF SUBMARINE HULL MATERIALS
Source: SOUTHWEST RESEARCH INSTITUTE FINAL RPT.; PROJ. No. 03-1375 DEPT. OF NAVY
Volume: ____ Number: ____
Date: OCT. 28, 1964 Pages: 104
These Data from Pages: 84, 9
(3) Units for Test Data: KIP-INCH-SEC - °F

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	Stress Cycle (7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL
1	-45.5	0.0	13,000	AT BASE OF NOTCH PROPAGATING RADIALLY INWARD	NOT GIVEN
2	-52.6	0.0	3,779		
3	-56.9	0.0	2,200		
4	-68.3	0.0	1,434		
5	-74.0	0.0	510		

(29) Method of Load Measurement: MEASUREMENT OF JACK PRESSURE GIVES MAGNITUDE OF APPLIED LOAD

(30) Basis for Stress Calculation: NET AREA AT NOTCH ROOT $f = P/A$

Ratio, Crack Propagation Life / Total Fatigue Life

(31) Failure Criterion: INITIATION OF FATIGUE CRACK AS DETECTED BY ULTRASONIC TESTING

WELDING DESCRIPTION

(19) Welding Process: NOT APPLICABLE
(19) Welding Gas Used: ______ (19) Welding Position: ______
(19) Electrode Type and Handling Description:
(20) Weld Defect Description:

Pass No.	(19) Electrode Size and Spec.	(19) Amps A.C.-D.C.	Volts	Speed of Welding	Back Chip. or Grinding Yes or No

(19) Polarity:
(24) Preheat Temperature:
Interpass Temperature:
(21) N.D.T. Observations:
(22) Weld Inspection:
(23) Weld Repair History:

(13) & (14) Surface Treatment, Finish, Coating:

(15) Mechanical and/or Thermal Stress Alteration Treatment Before or After Welding: PRELOADED WITH 102 KSI COMP. TO INDUCE TENSILE RESIDUAL STRESS AT THE NOTCH ROOT APPROXIMATELY EQUAL TO THE YIELD STRESS

FIG. 2.11b SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET – NOTCHED CYLINDRICAL BAR

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

WELDED SPECIMENS

Data Recorded on Fatigue Coding Form No 0081

BASE METAL PROPERTIES

(9) Specification Designation: U.S.S. T-1
Manufacturing Process: (ASTM A514F) not specified
Shape or Plate Description: 3/4" THK × 9" WIDE × 48" LONG
HEAT No. 735578

MECHANICAL PROPERTIES (COUPON)

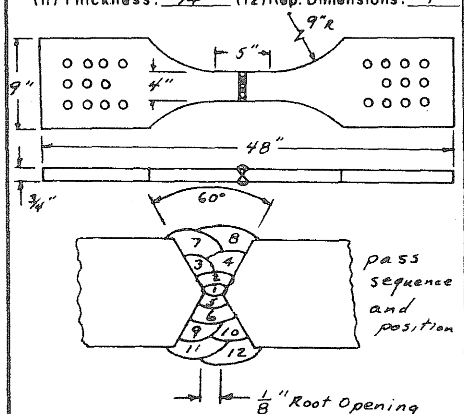
(4) Yield Point: 107.45
(5) Ultimate Strength: 116.15
Percent Red. of Area: not given
Percent Elong. in 2" Gage Length: 28.0

CHEMICAL COMPOSITION, Percent

C 0.17 Mn 0.71 P 0.012 S 0.020
Si 0.23 Ni 0.79 Cr 0.47 V 0.05
Mo 0.43 Cu 0.23 B 0.004

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: 3/4" (12) Rep. Dimensions: 4"



(16) Theoretical Stress Conc. Factor; K_t: NOT GIVEN
(17) Critical Stress Intensity Factor; K_c: NOT GIVEN

Fabrication, Spec., Notes, Remarks:
Edges machined to shape then drawfiled and polished with emery cloth

SPECIMEN PROPERTIES

Yield Point	Ultimate Str
	125.56
	125.92

AVE. FATIGUE STRENGTH

Stress Cycle: 0 → T

Cycles	Stress
100,000	47.2
2,000,000	22.2

K: 0.252

Reviewer: A. Liu Ck'd: DDM
Date: Nov. 11, 1966
Library Ref No: PROF. MUNSE

TEST CONDITIONS

(25) Environment: AIR
(26) Temperature: ROOM
(27) Loading Frequency: 100 → 180 cpm
(28) Type of Loading: AXIAL CONCENTRIC

(10) SPECIMEN TYPE: DAAABB
(1) BIBLIOGRAPHY NO.: 65-6 Sheet 5 of 9
Author(s): MUNSE, W.H.; STALLMEYER, J.E.; ROLFE, J.W.
Title: FATIGUE BEHAVIOR OF PLAIN PLATE AND BUTT-WELDED JOINTS IN T-1 STEEL
Source: UNIV. OF ILLINOIS REPORT FOR U.S. STEEL CORP.
Volume: Number:
Date: JANUARY, 1965 Pages: 1-53
These Data from Pages: Tables 1,2,3,8; Fig. 1a, 4
(3) Units for Test Data: KIP – INCH – SECOND – °F

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	(7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL
USS-11	0.0	+55.0	57,100	Toe of weld, crack propagated through thickness of specimen through the heat-affected zone into the base metal.	not given
USS-19	0.0	+55.0	59,100	↓	↓
USS-29	0.0	+55.0	64,500	↓	↓
USS-23	0.0	+40.0	213,300	↓	↓
" -1	0.0	+30.0	388,000	↓	↓
" -33	0.0	+30.0	594,400	↓	↓
" -9	0.0	+30.0	650,000	↓	↓
" -21	0.0	+25.0	1,090,000	↓	↓
" -27	0.0	+25.0	3,019,200	Premature failure in Pullhead	

\# Ratio, Crack Propagation Life / Total Fatigue Life

(29) Method of Load Measurement: Load on specimen was measured by means of a dynamometer on the machine.

(30) Basis for Stress Calculation: load on area of base metal

$$f_a = \frac{P}{A}$$

(31) Failure Criterion: Crack propagating approximately 1/2 through specimen tripped a microswitch stopping machine

WELDING DESCRIPTION

(19) Welding Process: Shielded metal arc
(19) Welding Gas Used: none (19) Welding Position: FLAT
(19) Electrode Type and Handling Description: Procedure P100-11018A
(20) Weld Defect Description: NOT GIVEN

Pass No.	(19) Electrode Size and Spec.	(19) Amps A.C.-D.C.	Volts	Speed of Welding	Back Chip. or Grinding Yes or No
1	E11018 1/8"φ	DC 125	20	3	YES, BEFORE PASS No. 5
2, 10, 11, 12	E11018 5/32"φ	DC 170	22	6.9-12.0	
3, 4, 6, 7, 8, 9	E11018 5/32"φ	DC 175	22	6.8-12.0	
5	E11018 1/8"φ	DC 140	22	6.2	

(19) Polarity: REVERSED
(24) Preheat Temperature: 150° – 200°
Interpass Temperature: 150° – 200°

(21) N.D.T. Observations:
(22) Weld Inspection: WELDS X-RAYED, NO DEFECTS FOUND

(23) Weld Repair History: NONE

(13) & (14) Surface Treatment, Finish, Coating: WELD REINFORCEMENT ON

(15) Mechanical and/or Thermal Stress Alteration Treatment Before or After Welding: NONE AFTER WELDING; THE STEEL IS A HEAT TREATED STEEL

FIG. 2.11c SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET – BUTT-WELDED PLATE

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

WELDED SPECIMENS

Data Recorded on Fatigue Coding Form No. ______

BASE METAL PROPERTIES

(9) Specification Designation: ASTM A-36

Manufacturing Process: ______

Shape or Plate Description: 14 WF 30 WITH COVER PLATES OF 9/16" THK. x 4½" WIDE x 4'-0" LONG

☆ MECHANICAL PROPERTIES (COUPON)

(4) Yield Point: 39.66

(5) Ultimate Strength: 61.53

Percent Red. of Area: 58.6%

Percent Elong. in 8" Gage Length: 30.9%

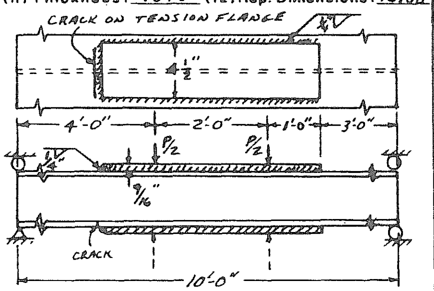
CHEMICAL COMPOSITION, Percent

C ____ Mn ____ P ____ S ____

Si ____

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: .375" (12) Rep. Dimensions: 13.88"



14 WF 30 ROLLED BEAM WITH COVER PLATES

(16) Theoretical Stress Conc. Factor; K_t: NOT GIVEN

(17) Critical Stress Intensity Factor; K_c: NOT GIVEN

Fabrication, Spec., Notes, Remarks:

☆ AVERAGE MECHANICAL PROPERTIES OF SPECIMENS CUT FROM THE FLANGE, COVER PLATES, AND WEBS

TESTING MACHINES WERE AMSLER PULSATORS

SPECIMEN PROPERTIES

Yield Point	Ultimate Str.

AVE. FATIGUE STRENGTH

Stress Cycle: ______

Cycles	Stress
100,000	
2,000,000	

K: ______

Reviewer: DDM Ck'd: ______

Date: 11/1/71

Library Ref No.: PROF. MUNSE'S LIBRARY

TEST CONDITIONS

(25) Environment: AIR

(26) Temperature: ROOM

(27) Loading Frequency: 260 - 800 cpm

(28) Type of Loading: FLEXURE

(10) SPECIMEN TYPE: NAAQEN

(1) BIBLIOGRAPHY NO.: 70-9 Sheet 1 of ___

Author(s): FISHER, J.W.; FRANK, K.H.; HIRT, M.A.; McNAMEE, B.M.

Title: EFFECT OF WELDMENTS ON THE FATIGUE STRENGTH OF STEEL BEAMS

Source: HIGHWAY RESEARCH BOARD – NATIONAL COOPERATIVE HIGH. RESEARCH PROG. REP. #102

Volume: ______ Number: ______

Date: 1970 Pages: 114

These Data from Pages: 4, 63, 74

(3) Units for Test Data: KIP - INCH - °F

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec. No.	Stress Cycle (6) Min.	(7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL
CRA 131	-6.0	+10.0	392,500	CRACK INITIATED IN THE TENSION FLANGE NEAR THE CENTER OF THE WIDTH AT THE TOE OF THE TRANSVERSE FILLET WELD CONNECTING THE COVER PLATE TO THE FLANGE. THE CRACK PROPAGATED INTO THE BEAM AND ALONG THE TOE OF THE WELD ACROSS THE FLANGE WIDTH.	NOT GIVEN
CRA 141	-6.0	+14.0	192,200		
CRA 144	-6.0	+14.0	176,100		
CRA 151	-6.0	+18.0	114,400		

* Ratio, Crack Propagation Life / Total Fatigue Life

(29) Method of Load Measurement: HYDRAULIC PRESSURE IN JACKS GAVE THE MAGNITUDE OF THE APPLIED LOAD. LOAD ADJUSTED TO GIVE THE STRAIN DESIRED

(30) Basis for Stress Calculation: NOMINAL FLEXURAL STRESS IN EXTREME FIBER OF THE BASE METAL AT THE END OF THE COVER PLATE. STRAINS WERE MEASURED AND LOAD ADJUSTED. f=εE

(31) Failure Criterion: AN INCREASE IN MIDSPAN DEFLECTION OF 0.020". CRACKED AREA WAS APPROXIMATELY 75% OF TOTAL FLANGE AREA

WELDING DESCRIPTION

(19) Welding Process: AUTOMATIC SUBMERGED ARC & SHIELDED METAL ARC

(19) Welding Gas Used: ______ (19) Welding Position: FLAT

(19) Electrode Type and Handling Description: L-60 5/64-IN. DIAMETER WIRE, 780 FLUX FOR LONGITUDINAL FILLET WELD — END FILLET WELDS PLACED MANUALLY WITH E7018 ELECTRODES

(20) Weld Defect Description: NONE

Pass No.	(19) Electrode Size and Spec.	(19) Amps A.C.-D.C.	Volts	Speed of Welding	Back Chip. or Grinding Yes or No
LONG. WELDS	L-60 5/64" ϕ 780 FLUX	350	30	16"/min	NO
TRANS. WELDS	E7018 5/32" ϕ				

(19) Polarity: NOT GIVEN

(24) Preheat Temperature: NONE, ROOM TEMP.

Interpass Temperature: NOT APPLIC.

(21) N.D.T. Observations:

(22) Weld Inspection: ALL WELDS SUBJECTED TO INSPECTION SIMILAR TO STATE HIGHWAY PROCEDURE

(23) Weld Repair History: ALL DEFECTIVE WELDS GOUGED OUT AND REWELDED

(13) & (14) Surface Treatment, Finish, Coating: NONE – AS ROLLED AND WELDED

(15) Mechanical and/or Thermal Stress Alteration Treatment Before or After Welding: NONE

FIG. 2.11d SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET – BEAM WITH FILLET-WELDED PARTIAL LENGTH COVER PLATES

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS
RIVETED AND BOLTED SPECIMENS

Data Recorded on Fatigue Coding Form No ......

BASE METAL PROPERTIES

(9) Specification Designation: ASTM A-514 B
Manufacturing Process: HT. No. 71L919 (5/16" PLT.)
HEAT No. 66M036 (1/2" PLATE)
Shape or Plate Description:
1/2" THK. CENTER PLATE
5/16" SIDE PLATES

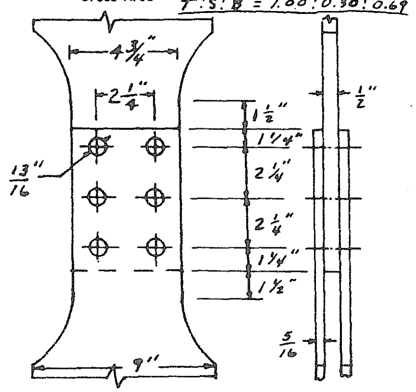
★ MECHANICAL PROPERTIES (COUPON)
(4) Yield Point: 118.1 (.2% offset)
(5) Ultimate Strength: 126.1
Percent Red. of Area: 58.4
Percent Elong. in 2" Gage Length: 34.0

CHEMICAL COMPOSITION, Percent

C 0.19 Mn 0.80 P 0.014 S 0.022
Si 0.24 Cr 0.50 Mo 0.20 V 0.05
B 0.004 Ti 0.013

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: .50" (12) Rep. Dimensions: 4.75"
(24) Ratio, Net Area / Gross Area: 0.62
T:S:B = 1.00:0.30:0.69



(16) Theoretical Stress Conc. Factor; K_t: NOT GIVEN
(17) Critical Stress Intensity Factor, K_c: NOT GIVEN

Fabrication, Spec., Notes, Remarks:
★ MECHANICAL PROPERTIES AND CHEMICAL COMPOSITION OF 1/2" THK. CENTER PLATE ONLY ARE GIVEN SINCE THIS WAS THE CRITICAL PLATE.
PLATES MACHINED TO FINAL SHAPE AFTER HOLES WERE DRILLED

SPECIMEN PROPERTIES

Yield Point	Ultimate Str

AVE. FATIGUE STRENGTH
Stress Cycle: C-T

Cycles	Stress
100,000	50.8
2,000,000	25.4

K: 0.231

Reviewer: R. S. Ck'd DDM
Date: APRIL 27, 1970
Library Ref. No.: 620.6 CEPST

TEST CONDITIONS

(25) Environment: AIR
(26) Temperature: Room
(27) Loading Frequency: 180 CPM
(28) Type of Loading: AXIAL

(10) SPECIMEN TYPE: JHACAA
(1) BIBLIOGRAPHY NO.: 69-2 Sheet 1 of 14
Author(s): BIRKEMOE, P.C.; MEINHEIT, D.F.; MUNSE, W.H.
Title: FATIGUE OF A-514 STEEL IN BOLTED CONNECTIONS
Source: ASCE – JOURNAL OF THE STRUCTURAL DIVISION
Volume: 95 Number: ST10
Date: OCT. 1969 Pages: 2011 – 2030
These Data from Pages: 2012 – 2017
(3) Units for Test Data: KIPS – INCHES –

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec No	(6) Min.	(7) Max.	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL TFL
Q3B-8	-50.0	+50.0	123,000	CRACK INITIATED ON THE FAYING SURFACE OF THE CENTER PLATE AT OR NEAR THE CRITICAL NET SECTION, POSSIBLY DUE TO FRETTING BETWEEN PLATES.	NOT GIVEN
Q3B-3	-50.0	+50.0	111,000		
Q3B-10	-35.0	+35.0	418,000		
Q3B-9	-28.0	+28.0	1,561,000		

(Stress Cycle: columns (6) Min. and (7) Max.)

(29) Method of Load Measurement: DYNAMOMETER ON FATIGUE MACHINE USED TO MEASURE LOAD ON SPECIMEN

(30) Basis for Stress Calculation: NET SECTION STRESS
$f = P/A$ A = net section area (nominal)

* Ratio, Crack Propagation Life / Total Fatigue Life

(31) Failure Criterion: MACHINE SHUTOFF DUE TO EXCESSIVE DEFORMATION CAUSED BY FATIGUE CRACK.

FASTENERS

(19) Type: BOLTS (19) Specification & Country: ASTM A325 U.S.A. (19) Diameter: 3/4 IN.
Yield Strength: ★★ (19) Ultimate Strength: ★★ Elongation, %: ★★ Hardness: ★★
Chemical Comp.: C___ Mn___ P___ S___ Si___ (10) Hole Clearance: 1/16" (HOLE DIA. = 13/16")
(20) Clamping Force: 43.5 KIPS (10) Hole Preparation: DRILLED

RIVETS

(19) Head Type:
(20) Manufacture: Hot Formed___ Cold Formed___
(20) Driving: Hot___ Cold___
Manual___ Machine___
Other:

BOLTS

(19) Type: HIGH STRENGTH – HEX HEAD
(21) Type of Thread: 10 UNC (22) Type of Nut: HEAVY-HEX
(22) No. and Type of Washers: 1 HARDENED
(23) No. of Threads in Grip: 2
(20) Installation Procedure: TURN OF NUT – SNUG + 1/2 TURN

(13) & (14) Faying Surface Treatment, Cleaning, Finish and/or Coating: CLEANED WITH ACETONE TO REMOVE ANY CUTTING OIL REMAINING AFTER MACHINING + DRILLING

(15) Mechanical and/or Thermal Treatment Before or After Fabrication: NONE

★★ BOLTS EXCEEDED ALL MINIMUM MECHANICAL REQUIREMENTS FOR ASTM A325 FASTENERS.

FIG. 2.11e SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET – BOLTED DOUBLE LAP JOINT

FATIGUE DATA SUMMARY – DEPARTMENT OF CIVIL ENGINEERING – UNIVERSITY OF ILLINOIS – URBANA, ILLINOIS

RIVETED AND BOLTED SPECIMENS

Data Recorded on Fatigue Coding Form No ______

BASE METAL PROPERTIES

(9) Specification Designation: ASTM A-7-55T
Manufacturing Process:
Shape or Plate Description: 3/8" THK. PLATE FOR CENTER PLATE

MECHANICAL PROPERTIES (COUPON)

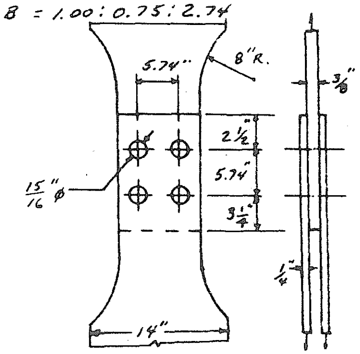
(4) Yield Point: 45.1
(5) Ultimate Strength: 66.5
Percent Red. of Area: 51.4
Percent Elong. in 8" Gage Length: 29.0

CHEMICAL COMPOSITION, Percent

C 0.27 Mn 0.40 P 0.016 S 0.036
Si

SPECIMEN AND FRACTURE DETAILS

(11) Thickness: .375 (12) Rep. Dimensions: 11.48"
(24) Ratio, Net Area / Gross Area: 0.837
T:S:B = 1.00:0.75:2.74



SPECIMEN TYPE 1FR

(16) Theoretical Stress Conc. Factor; K_t: NOT GIVEN
(17) Critical Stress Intensity Factor, K_c: NOT GIVEN

Fabrication, Spec., Notes, Remarks:
FABRICATED IN SHOP OF A STEEL FABRICATOR
EDGES WERE MILLED

SPECIMEN PROPERTIES

Yield Point	Ultimate Str
—	62.1

AVE FATIGUE STRENGTH

Stress Cycle: 0-T

Cycles	Stress
100,000	25.5
2,000,000	14.5

K.

Reviewer: J.F.P. Ck'd DDM
Date: MAY 10, 1965
Library Ref No: 620.1 IL6 PROF. MUNSE

TEST CONDITIONS

(25) Environment: AIR
(26) Temperature: ROOM
(27) Loading Frequency: 200 cpm
(28) Type of Loading: AXIAL

(10) SPECIMEN TYPE GEACAA
( ) BIBLIOGRAPHY NO 64-7 Sheet 1 of 2
Author(s): PAROLA, J.F.; CHESSON, E. JR.; MUNSE, W.H.
Title: EFFECT OF BEARING PRESSURE ON FATIGUE STRENGTH OF RIVETED CONNECTIONS
Source: UNIVERSITY OF ILLINOIS – BULLETIN #481
Volume Number
Date: 1964 Pages: 85
These Data from Pages: 58

(3) Units for Test Data: KIPS-INCHES

INDIVIDUAL FATIGUE TEST RESULTS

(2) Spec No	Stress Cycle (6) Min.	Stress Cycle (7) Max	(8) Cycles to Failure	(32) Location of Fracture	(33) CPL/TFL
1FR1	0.0	+30.0	56,900	CRACK INITIATED AT THE FIRST ROW (INDICATED ON FIGURE) OF RIVET HOLES IN THE CENTER PLATE AND PROPAGATED TOWARD THE EDGE AND CENTER OF THE PLATE.	
1FR2	0.0	+28.0	71,400		
1FR3	0.0	+28.0	80,900		
1FR4	0.0	+18.0	417,200		
1FR5	0.0	+20.0	315,700		
1FR6	0.0	+18.0	685,600		

* Ratio, Crack Propagation Life / Total Fatigue Life

(31) Failure Criterion: WHEN CRACK BECAME VISIBLE

(29) Method of Load Measurement: DYNAMOMETER ON MACHINE USED TO OBTAIN LOAD ON SPECIMEN.

(30) Basis for Stress Calculation: NET SECTION OF PLATE: $f = P/A$
A = (SPEC. WIDTH − 2 HOLE ϕ's) THK.

FASTENERS

(19) Type: RIVET (19) Specification & Country: ASTM A-141-55 (19) Diameter: 7/8" NOMINAL
Yield Strength: 29.6 (19) Ultimate Strength: 58.5 Elongation, %: 26.5 in 8" Hardness:
Chemical Comp.: C ___ Mn ___ P 0.04 S 0.05 Si ___ (10) Hole Clearance: 1/16"
(20) Clamping Force: ___ (10) Hole Preparation: DRILLED – 15/16" DIA.

RIVETS

(19) Head Type: BUTTON HEAD
(20) Manufacture: Hot Formed ✓ Cold Formed ___
(20) Driving: Hot ✓ Cold ___
Manual ___ Machine ✓ 50 TON-HORSE-SHOE TYPE
Other: UNUSUAL CARE TAKEN IN DRIVING RIVETS

BOLTS

(19) Type:
(21) Type of Thread: ___ (22) Type of Nut:
(22) No. and Type of Washers:
(23) No. of Threads in Grip:
(20) Installation Procedure:

(13) & (14) Faying Surface Treatment, Cleaning, Finish and/or Coating: NONE

(15) Mechanical and/or Thermal Treatment Before or After Fabrication: NONE

FIG. 2.11f SAMPLE OF COMPLETED FATIGUE DATA SUMMARY SHEET – RIVETED DOUBLE LAP JOINT

DETAILED SPECIMEN DATA

Category	Column	
1	1-6	Bibliography Number
2	7-12	Specimen Number
3	13	Units for Test Data (kip - inch, kg - mm, MN - m)
4	14-16	Base Metal Yield Strength
5	17-19	Base Metal Tensile Strength
6	20-24	Cyclic Minimum Stress
7	25-29	Cyclic Maximum Stress
8	30-34	Cycles to Failure

MATERIAL & SPECIMEN DESCRIPTION

9	35-40	Base Metal Specification
10	41-46	Description of Test Specimen
11	47	Material Thickness (at critical location in specimen)
12	48	Representative Specimen Dimension (plate width; beam depth; etc.)
13	49-50	Surface Treatment
14	51	Surface Finish or Coating
15	52-53	Thermal and/or Mechanical Residual Stress Alteration Treatment
16	54	Theoretical Stress Concentration Factor, K_t
17	55-57	Critical Stress Intensity Factor, K_c
18	58	(Not Assigned)

SPECIMEN FABRICATION DESCRIPTION

		WELDED	RIVETED OR BOLTED
19	59-63	Welding Process Description	Fastener Description
20	64-65	Weld Defect Description	Installation Procedure, Clamping Force
21	66	Nondestructive Test Observation	Type of Thread
22	67	Weld Inspection Rating	Nut, Washer Details
23	68	Weld Repair History	No. of Threads in Grip
24	69	Preheat Temperature	Ratio of Net to Gross Area

TEST CONDITIONS & FAILURE DESCRIPTION

25	70	Test Environment
26	71	Test Temperature
27	72	Frequency of Loading
28	73	Type of Loading
29	74	Method of Measurement (direct load record; strain gage record; etc.)
30	75-76	Basis for Stress Calculation (nominal shear on fasteners; direct stress on net or gross area, etc.)
31	77	Failure Criterion (crack initiation; complete fracture; etc.)
32	78-79	Failure Location
33	80	Ratio, Crack Propagation Life to Total Fatigue Life

FIG. 2.12 CLASSIFICATION OF FATIGUE SPECIMEN DATA RECORDED ON COMPUTER PUNCH CARDS

CATEGORY 10

GENERAL DESCRIPTION OF TEST SPECIMEN

Column 41 SPECIMEN TYPE AND LOADING

PLAIN MATERIAL

A Axially Loaded
B Loaded in Flexure
C Loaded in Torsion
1 Combined

WELDED JOINTS AND CONNECTIONS

D Axially Loaded
E Loaded in Flexure
F Loaded in Torsion
2 Combined

RIVETED (OR PINNED) JOINTS AND CONNECTIONS

G Axially Loaded
H Loaded in Flexure
I Loaded in Torsion
3 Combined

BOLTED JOINTS AND CONNECTIONS

J Axially Loaded
K Loaded in Flexure
L Loaded in Torsion
4 Combined

WELDED ASSEMBLAGES

M Axially Loaded
N Loaded in Flexure
O Loaded in Torsion
5 Combined

RIVETED (OR PINNED) ASSEMBLAGES

P Axially Loaded
Q Loaded in Flexure
R Loaded in Torsion
6 Combined

BOLTED ASSEMBLAGES

S Axially Loaded
T Loaded in Flexure
U Loaded in Torsion
7 Combined

FIG. 2.13a SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS — GENERAL DESCRIPTION OF SPECIMEN TYPE AND LOADING

DETAILED DESCRIPTION OF TEST SPECIMEN

PLAIN MATERIAL

Column 42

OVERALL CONFIGURATION

A PLATE

BAR
B Rectangular
C Square
D Circular
E Eye
F Deformed

TUBE (Seamless)
G Rectangular
H Square
I Circular (pipe)

WIRE
J Single
K Strand
L Rope

FASTENER
M Bolt
N Rivet

SHAPES
O I
P Cruciform
Q Tee
R Angle (equal legs)
S Angle (unequal legs)
T Channel
U Zee
V Corrugated Sheet
W Ribbed Sheet (rectangular)
Y Ribbed Sheet (trapezoidal)
Z Cellular Sheet

Column 43

SURFACE OR CROSS SECTION DETAIL

X NONE, NOT APPLICABLE OR SPECIFIED

NOTCH
A External
B Internal
C Platelet
D Simulated Undercut
E Simulated Butt Joint
F Simulated Attachment
G Simulated Lap Joint

THREADS
H Straight
I Tapered

DEFORMED BAR PATTERN
J Pattern 1
K Pattern 2
L Pattern 3
M Pattern 4
N Pattern 5
O Pattern 6

WIRE CORE
P Rope
Q Strand

Column 44

GEOMETRY OF DETAIL

X NONE, NOT APPLICABLE OR SPECIFIED

NOTCH SHAPE
A V (triangular)
B U
C Y
D Circular
E Elliptical
F Rectangular with Saw-Cut
G Circular with Saw-Cut
H Irregular (flame-cut)
S Rectangular

FILLET
I 45°
J 90°
K Concave
L Convex

THREAD TYPE
American National
M Unspecified
N Fine
O Coarse
P Whitworth (British)
Q Square
R Acme

Column 45

LOCATION OF DETAIL

X NONE, NOT APPLICABLE OR SPECIFIED

LOCATION OF EXTERNAL NOTCH
A One Face
B Both Faces
C One Edge
D Both Edges
E All Around
F Partially Around

LOCATION OF INTERNAL NOTCH
G Face Centerline
H Offset From Face Centerline
I Multiple Locations on Face
J Edge Centerline
K Offset from Edge Centerline

LOCATION ALONG LENGTH
L All Along
M Along Portion

LOCATION IN SHAPES
N Flange (element supported on one edge)
O Web (element supported on two edges)
P Both Flange and Web

Column 46

FABRICATION OF DETAIL OR MEMBER

X NONE, NOT APPLICABLE OR SPECIFIED

FABRICATION OF DETAIL
A Drilled
B Drilled and Reamed
C Drilled and Tapped
D Flame-Cut
E Saw-Cut
F Punched
G Pressed
H Sheared
I Machined
J Upset

FABRICATION OF MEMBER
K Cold Rolled
L Hot Rolled
M Forged
N Extruded
O Machined
P Machined From Deposited Weld Metal
Q Cast

FIG. 2.13b SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS — DETAILED DESCRIPTION OF PLAIN MATERIAL

DETAILED DESCRIPTION OF TEST SPECIMEN

WELDED JOINTS AND CONNECTIONS

Column 42

OVERALL CONFIGURATION

BUTT JOINT
- A Equal Thickness and Width
- B Equal Diameter
- C Transition in Width
- D Transition in Thickness
- E Transition in Thickness and Width
- F Unequal Width
- G Unequal Thickness
- H Unequal Thickness and Width
- I Unequal Diameter

REDUCED SECTION BUTT JOINT
- J Hourglass
- K Hourglass Notched
- L Cylindrical
- M Rectangular (reduced thickness)
- W Cylindrical Notched

LAP JOINT
- N Single
- O Double
- P Multiple

SPLICE
- Q Angle
- R Sleeve

TEE JOINT
- S Tee
- T Cruciform

BUTT JOINT WITH NOTCH
- U Saw-cut Slot in Weld Parallel to Weld Axis (with or without hole)
- V Hole Through Weld Perpendicular to Plate Surface

- Y HANGER CONNECTION

Column 43

TYPES OF MEMBERS JOINED

X NONE, NOT APPLICABLE OR SPECIFIED

BUTTED OR LAPPED MEMBERS
- A Plates and/or Bars
- B Circular Bars
- C Deformed Bars
- D Rectangular Tubes
- E Circular Tubes (pipes)

MEMBERS LAPPED WITH PLATES OR SHAPES
- F Angle to Plate
- G Channel to Plate
- H I Section to Plate
- I Zee Section to Plate
- J Tee Section to Plate
- K Rectangular Tube to Plate
- L Circular Tube to Plate
- M Angle to Angle
- N Channel to Channel
- O I to I
- P Zee to Zee
- Q Tee to Tee

HANGER CONNECTION
- R Tee to Tee
- S Tee to I
- T Angle to Angle

Column 44

TYPE OF WELD

X NONE, NOT APPLICABLE OR SPECIFIED

GROOVE

Full Penetration
- A With Reinforcement
- B Without Reinforcement
- C With Contoured Reinforcement

Partial Penetration
- D With Reinforcement
- E Without Reinforcement
- F With Contoured Reinforcement

FILLET
- G Single Pass
- H Multiple Pass

PLUG
- I Fillet
- J Filled

SLOT
- K Fillet
- L Filled

- M Edge
- N Spot
- O Seam

Column 45

CONFIGURATION OF WELD

X NONE, NOT APPLICABLE OR SPECIFIED

GROOVE
- A Single V
- B Double V
- C Single Bevel
- D Double Bevel
- E Single U
- F Double U
- G Single J
- H Double J

Square Butt
- I One Side
- J Both Sides

FILLET
- K Continuous

Intermittent
- L Chain
- M Staggered

Column 46

ORIENTATION OF WELD WITH RESPECT TO DIRECTION OF LOAD OR REPORTED DIRECT STRESS

X NONE, NOT APPLICABLE OR SPECIFIED

- A Longitudinal
- B Transverse
- C Oblique
- D Longitudinal and Transverse
- E Longitudinal and Oblique
- F Transverse and Oblique
- G Longitudinal, Transverse and Oblique
- H Multiple Directions
- I All Around

FIG. 2.13c SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS — DETAILED DESCRIPTION OF WELDED JOINTS AND CONNECTIONS

DETAILED DESCRIPTION OF TEST SPECIMEN

WELDED ASSEMBLAGES

Column 42

OVERALL CONFIGURATION

PLAIN SHAPES

A I
B Cruciform
C Tee
D Angle (equal legs)
E Angle (unequal legs)
F Channel
G Zee

WELDED SHAPES

H I
I Cruciform
J Tee
K Angle (equal legs)
L Angle (unequal legs)
M Channel
N Zee
T Box or Rectangular Tube
U Circular Tube

O PLATE

BAR

P Rectangular
Q Circular

TUBE (seamless)

R Rectangular
S Circular

Column 43

TYPE OF ATTACHMENT OR DETAIL

X NONE, NOT APPLICABLE OR SPECIFIED

COVER PLATE

Partial Length
A Square End
B Tapered End
C Feathered End
Circular End
D Concave
E Convex
F Full Length

STIFFENER

G Transverse
H Longitudinal
I Longitudinal and Transverse

SPLICE

J Without Cope Hole
K With Cope Hole
L With Cope Holes Offset

ATTACHMENT TO PLATE OR SHAPE

M Plate or Bar
N Studs
O Angle
P Channel
Q I
R Tee
S Zee
T Spiral Wire

MEMBER ATTACHED TO MEMBER

U Tubes at 90° Angle
V Tubes at Oblique Angle

Column 44

CONFIGURATION OR LOCATION OF ATTACHMENT OR DETAIL

X NONE, NOT APPLICABLE OR SPECIFIED

ATTACHMENT TO PLATE

A One Face
B Both Faces
C One Edge
D Both Edges
E All Around

ATTACHMENT TO SHAPES

Web
F One Side
G Both Sides
One Flange
H One Side
I Both Sides
Both Flanges
Q One Side
R Both Sides

J One Flange and One Side of Web
K One Flange and Both Sides of Web
L Both Flanges and Both Sides of Web

FLANGE SPLICE DETAIL

N Thickness Transition
O Width Transition
P Both Thickness and Width Transition

WEB SPLICE DETAIL

S Thickness Transition

Column 45

TYPE OF WELD

X NONE, NOT APPLICABLE OR SPECIFIED

GROOVE

Full Penetration
A Without Reinforcement
B With Reinforcement
Partial Penetration
C Without Reinforcement
D With Reinforcement

FILLET

E Continuous
Intermittent
F Chain
G Staggered

PLUG

H Fillet
I Filled

SLOT

J Fillet
K Filled

L Weld Bead

STUD

M Stud

Column 46

CONFIGURATION OR ORIENTATION OF WELD

X NONE, NOT APPLICABLE OR SPECIFIED

CONFIGURATION

A Single V
B Double V
C Single Bevel
D Double Bevel
E Single U
F Double U
G Single J
H Double J
Square Butt
I One Side
J Both Sides

ORIENTATION

K Longitudinal
L Transverse
M Oblique
N Longitudinal and Transverse
O Longitudinal and Oblique
P Transverse and Oblique
0 Longitudinal, Transverse and Oblique
R Multiple Directions
S All Around

FIG. 2.13d SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS— DETAILED DESCRIPTION OF WELDED ASSEMBLAGES

DETAILED DESCRIPTION OF TEST SPECIMEN

RIVETED OR BOLTED JOINTS AND CONNECTIONS

Column 42

OVERALL CONFIGURATION

LAP JOINTS

Short Joints (< 4 rows)

One Row of Fasteners
- A Fastener in single shear
- B Fastener in double shear
- C Fastener in multiple shear

Two Rows of Fasteners
- D Fastener in single shear
- E Fastener in double shear
- F Fastener in multiple shear

Three Rows of Fasteners
- G Fastener in single shear
- H Fastener in double shear
- I Fastener in multiple shear

Long Joints (≥ 4 rows)
- J Fastener in single shear
- K Fastener in double shear
- L Fastener in multiple shear

M HANGER CONNECTION

N END PLATE CONNECTION

Column 43

TYPE OF MEMBERS JOINED

- X NOT SPECIFIED
- A Plates

MEMBERS CONNECTED TO PLATES OR SHAPES
- B I to Plate
- C Tee to Plate
- D Angle to Plate
- E Channel to Plate
- F Zee to Plate
- G Tube to Plate
- H I to I
- I Tee to Tee
- J Angle to Angle
- K Channel to Channel
- L Zee to Zee
- M Tube to Tube

HANGER CONNECTION
- N Tee to Tee
- O Tee to I
- P Angle to Angle

Column 44

CONFIGURATION OF FASTENERS (No. of Lines of Fasteners)

- X NOT SPECIFIED

RECTANGULAR PATTERN
- A No. of Lines Not Specified
- B 1
- C 2
- D 3
- E 4
- F > 4

STAGGERED PATTERN
- G No. of Lines Not Specified
- H 2
- I 3
- J 4
- K > 4

Column 45

HOLE CLEARANCE

- X NOT APPLICABLE, NOT SPECIFIED
- A Standard (1/16 in.)
- B Less Than Standard (< 1/16 in.)
- C Above Standard (> 1/16 in.)
- D Slotted Holes

Column 46

HOLE FABRICATION

- X NOT APPLICABLE, NOT SPECIFIED
- A Drilled
- B Punched
- C Subpunched and Reamed
- D Drilled and Reamed
- E Flame-Cut

FIG. 2.13e SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS—DETAILED DESCRIPTION OF RIVETED, BOLTED JOINTS AND CONNECTIONS

DETAILED DESCRIPTION OF TEST SPECIMEN

RIVETED OR BOLTED ASSEMBLAGES

Column 42

OVERALL CONFIGURATION

PLAIN SHAPES
- A I
- B Cruciform
- C Tee
- D Angle (equal legs)
- E Angle (unequal legs)
- F Channel
- G Zee

BUILT UP SECTIONS
- I I
- J Box
- K Double Angle
- L Tee

CRUCIFORM
- M Angles and Plates
- N Tees

- O PLATE
- P BAR
- Q TUBE
- R OTHERS

Column 43

TYPE OF ATTACHMENT OR DETAIL

X NONE, NOT SPECIFIED

COVER PLATE
- A Partial Length
- B Full Length

STIFFENER
- D Transverse
- E Longitudinal
- F Transverse and Longitudinal

I SPLICE

ATTACHMENT TO PLATE OR SHAPE
- J Plate or Bar
- K Angle
- L Channel
- M I
- N Tee
- O Zee

Column 44

CONFIGURATION OR LOCATION OF DETAIL

X NONE, NOT SPECIFIED

ATTACHMENT TO PLATE
- A One Face
- B Both Faces

ATTACHMENT TO SHAPES

Web
- C One Side
- D Both Sides

One Flange
- E One Side
- F Both Sides

Both Flanges
- G One Side
- H Both Sides

- I Flange and One Side of Web
- J Flange and Both Sides of Web
- K Both Flanges and One Side of Web
- L Both Flanges and Both Sides of Web

SPLICE
- N Web
- O Flange
- P Web and Flange

Column 45

HOLE CLEARANCE

X NOT APPLICABLE, NOT SPECIFIED

- A Standard (1/16 in.)
- B Less Than Standard ($<$ 1/16 in.)
- C Above Standard ($>$ 1/16 in.)
- D Slotted Holes

Column 46

HOLE FABRICATION

X NOT APPLICABLE, NOT SPECIFIED

- A Drilled
- B Punched
- C Subpunched and Reamed
- D Drilled and Reamed
- E Flame-Cut

FIG. 2.13f SYSTEM FOR CLASSIFICATION AND CODING OF TEST SPECIMENS— DETAILED DESCRIPTION OF RIVETED, BOLTED ASSEMBLAGES

SPECIMEN TYPE--AAXXXL

--Plain plate in as rolled condition, no stress raisers
--Tested under axial load

CODE	DESCRIPTION
A	Plain material, axially loaded
A	Specimen configuration, plate
X	Stress raising detail studied: none
X	Geometry of detail: not applicable
X	Location of detail: not applicable
L	Specimen fabrication method: hot rolled

SPECIMEN TYPE--ADAAEI

--Circular bar machined from plain plate with a machined V-shaped circumferential notch
--Tested under axial load

CODE	DESCRIPTION
A	Plain material, axially loaded
D	Circular bar
A	Detail studied: external notch
A	Notch geometry: triangular-V
E	Notch location: all around
I	Notch fabrication: machined

SPECIMEN TYPE--DAAABB

--Full penetration transverse double-V butt-welded plate with reinforcement in place
--Tested under axial load

CODE	DESCRIPTION
D	Welded connection, axially loaded
A	Butt joint, equal thickness and width
A	Members joined: plates
A	Full penetration groove weld with reinforcement
B	Double V groove
B	Load transverse to weld axis

FIG. 2.14 EXAMPLES OF CODING FOR VARIOUS TYPES OF FATIGUE TEST SPECIMENS

SPECIMEN TYPE--NAAQEN

--Rolled WF section with partial length cover plates attached with continuous fillet welds
--Tested in flexure

CODE	DESCRIPTION
N	Welded assemblage, loaded in flexure
A	Plain (not welded) I shape
A	Partial length cover plates with square ends
Q	Cover plates on one side of both flanges
E	Attached with continuous fillet weld
N	Weld oriented both transverse and longitudinal with respect to axis of beam

SPECIMEN TYPE--JHACAA

--Lapped plates with three rows and two lines of 3/4 inch bolts in double shear
--Tested under axial load

CODE	DESCRIPTION
J	Bolted connection, axially loaded
H	Lap joint, three rows of bolts in double shear
A	Members joined: plates
C	Bolts in rectangular pattern, two lines
A	Standard (1/16 inch) hole clearance
A	Hole fabrication: drilled

SPECIMEN TYPE--GEACAA

--Double lapped plates with two rows and two lines of 7/8 inch rivets in double shear
--Tested under axial load

CODE	DESCRIPTION
G	Riveted connection, axially loaded
E	Lap joint, two rows of rivets in double shear
A	Members joined: plates
C	Rivets in rectangular pattern, two lines
A	Standard (1/16 inch) hole clearance
A	Hole fabrication: drilled

FIG. 2.14 EXAMPLES OF CODING FOR VARIOUS TYPES OF FATIGUE TEST SPECIMENS

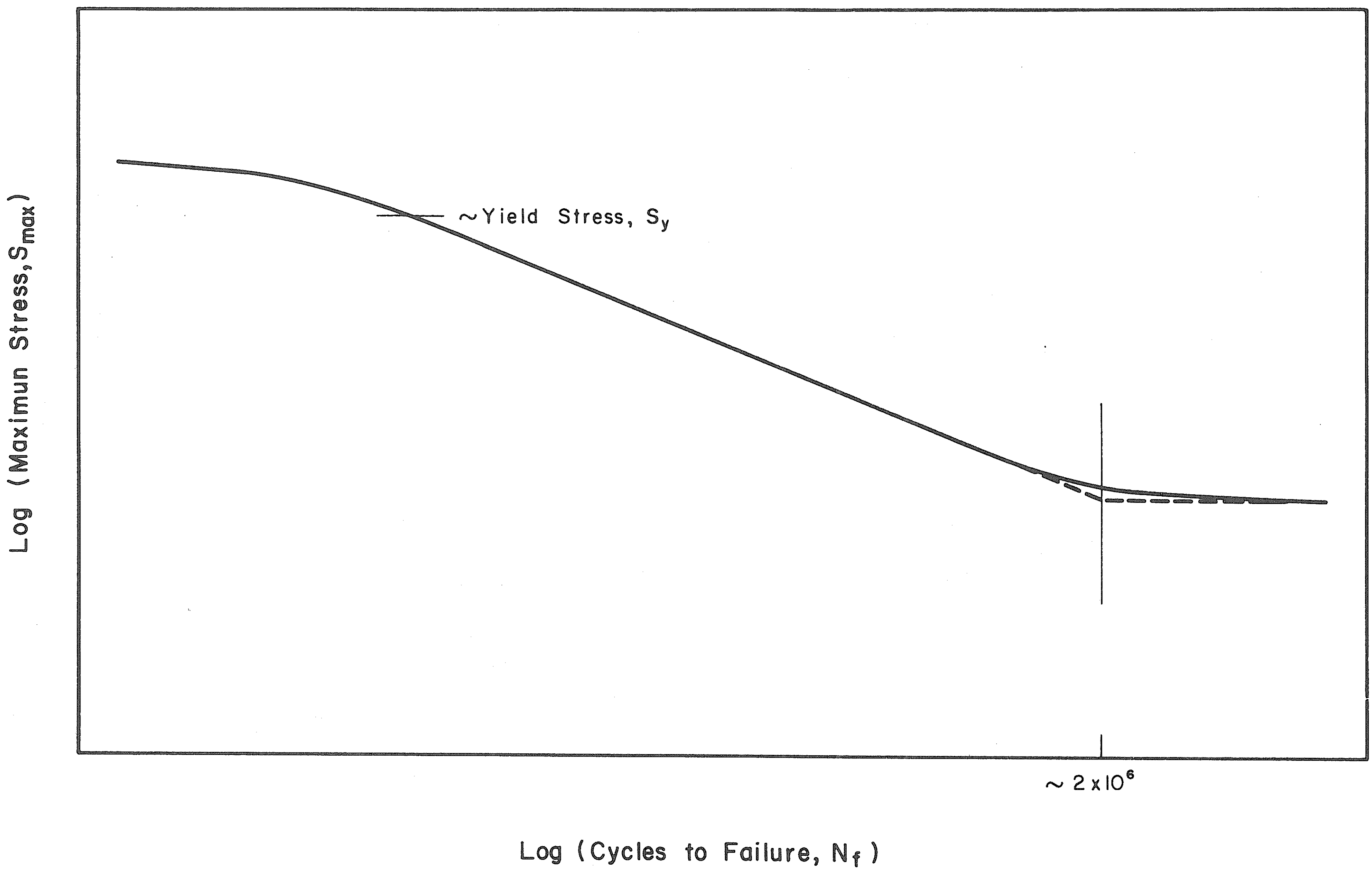


FIG. 3.1 ILLUSTRATION OF REPRESENTATIVE S-N CURVE FOR STEEL

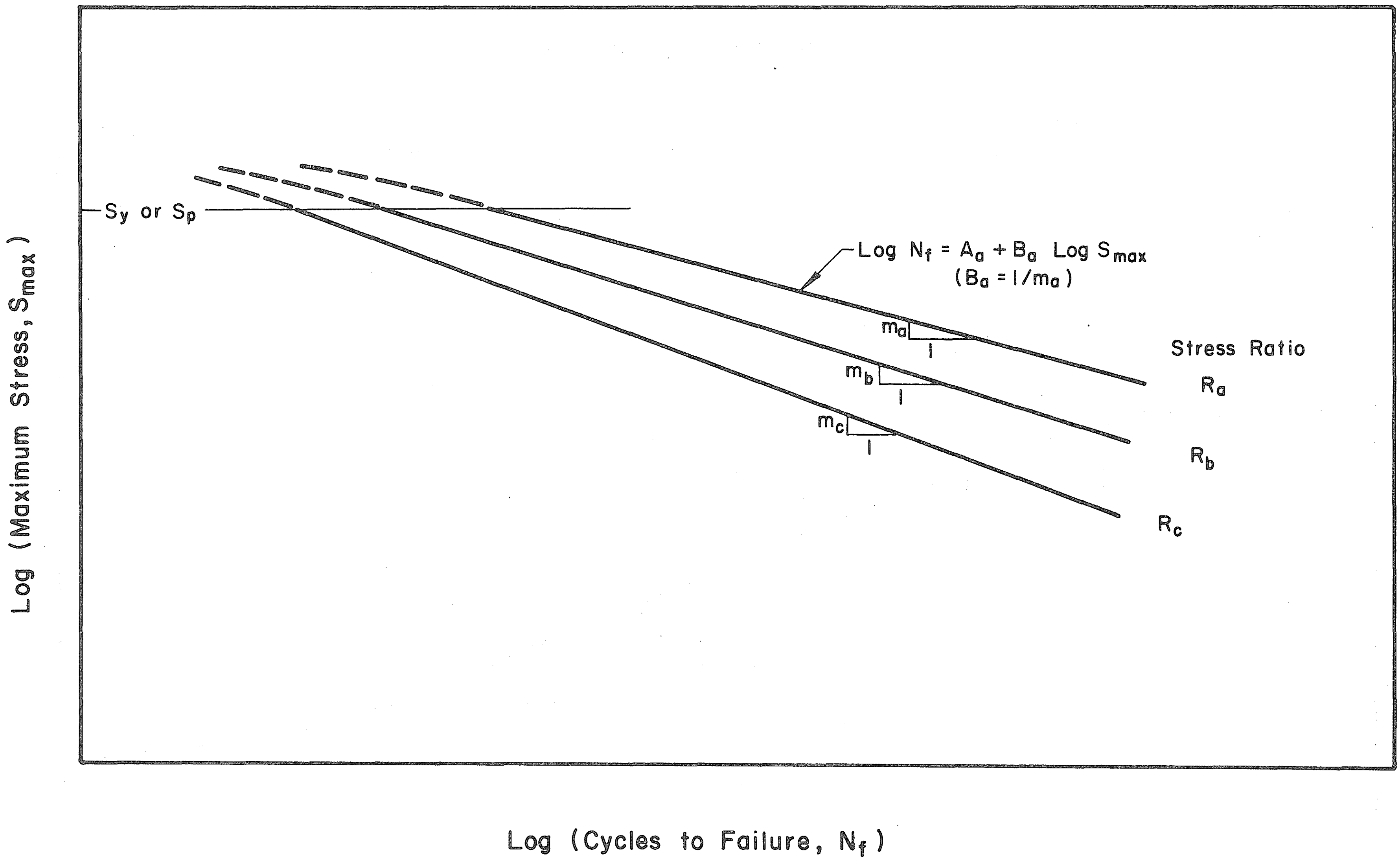


FIG. 3.2 REPRESENTATIVE FINITE LIFE S-N CURVES FOR TESTS CONDUCTED AT VARIOUS CONSTANT STRESS RATIOS

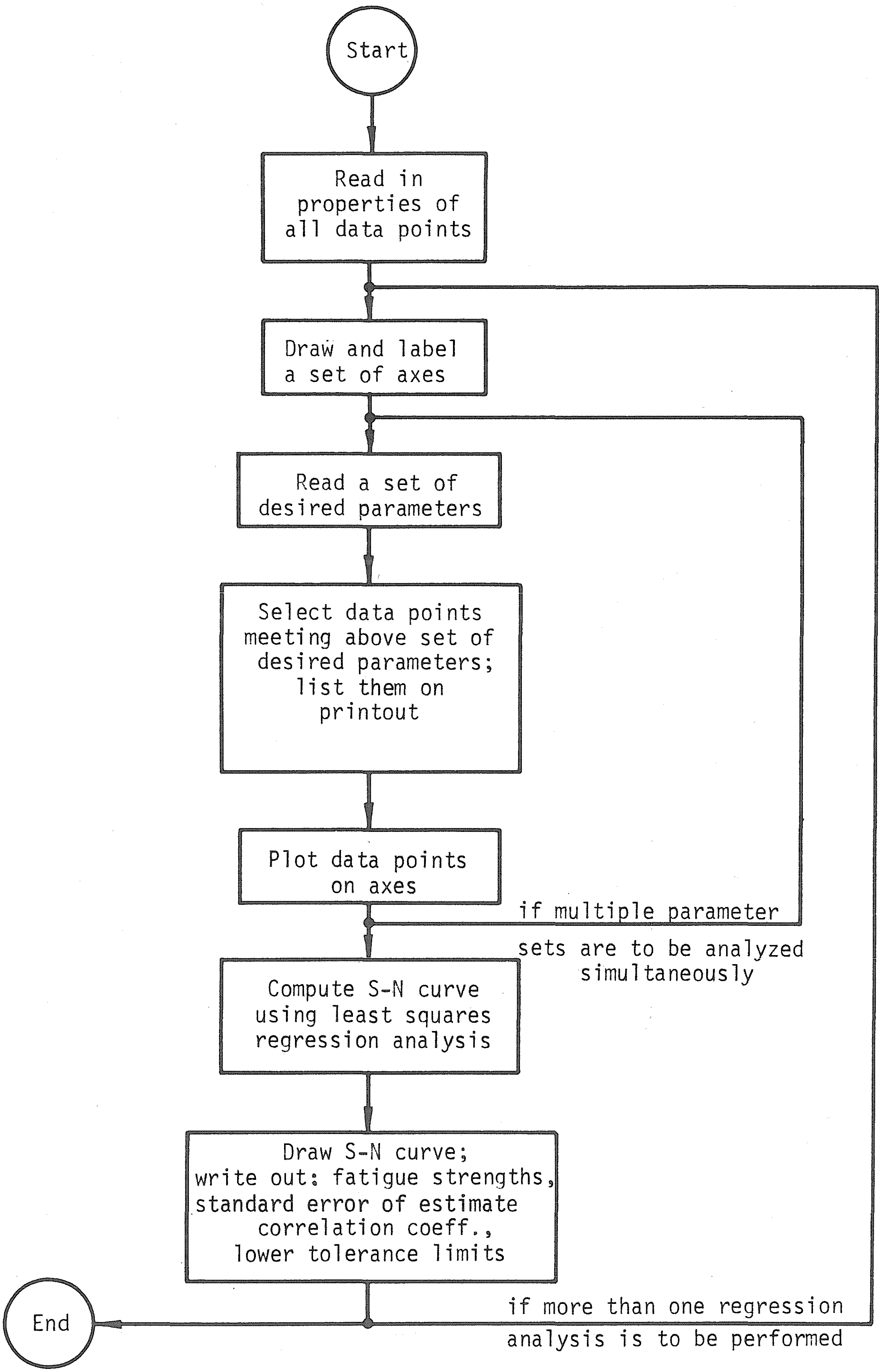


FIG. 3.3 GENERAL FLOW DIAGRAM FOR COMPUTER PROGRAM

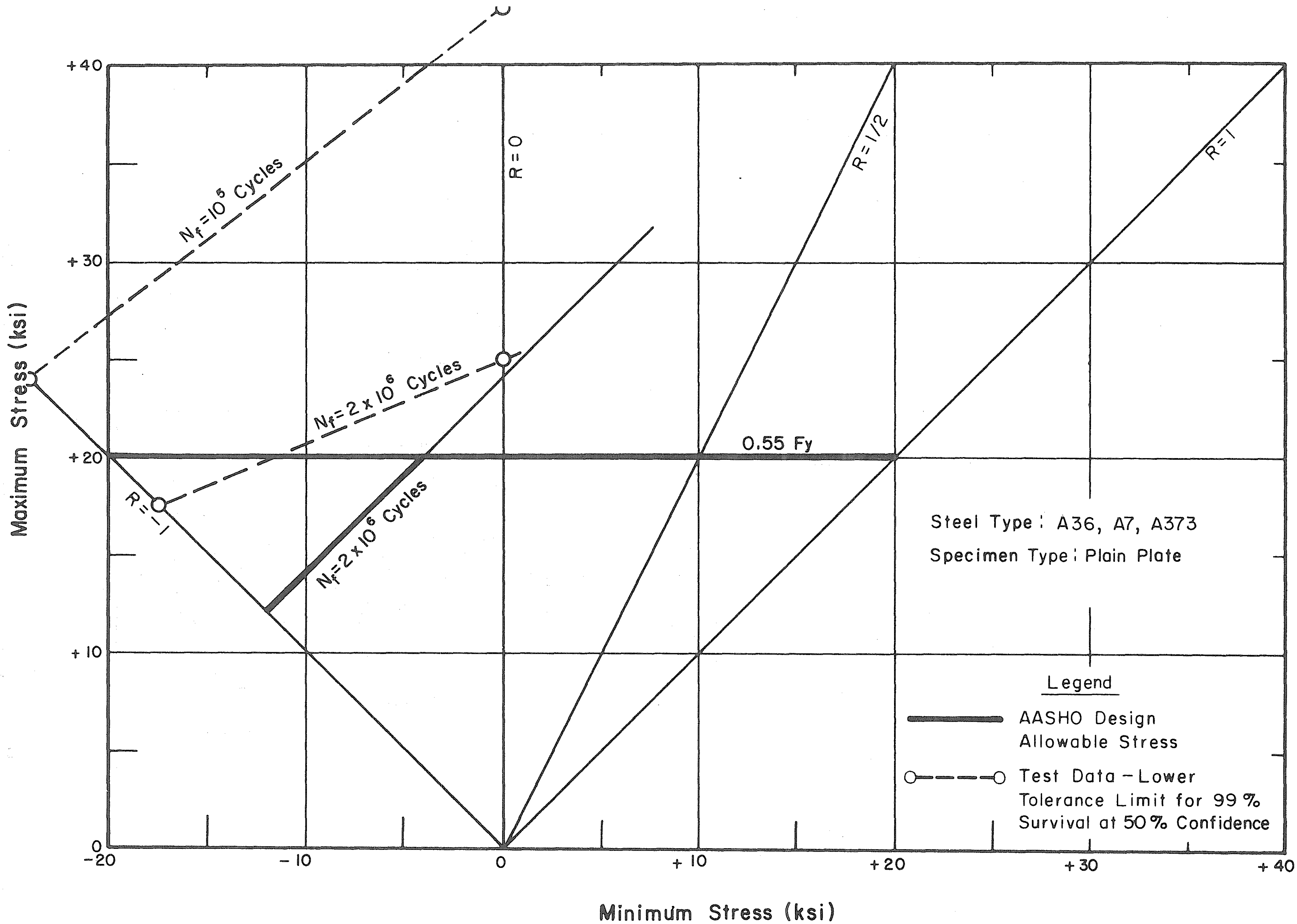


FIG. 4.1 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR PLAIN PLATE MATERIAL, STRUCTURAL CARBON STEEL

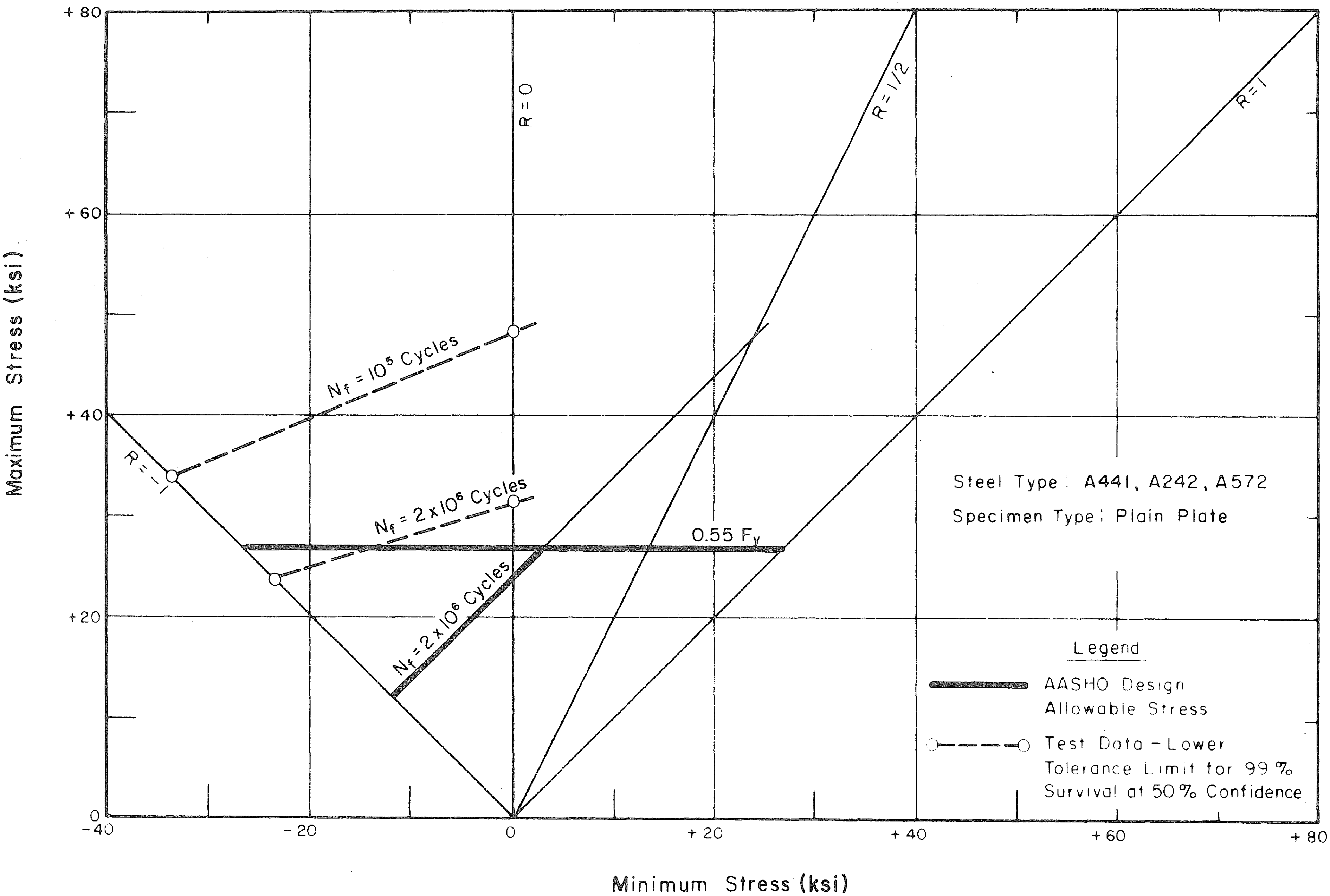


FIG. 4.2 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR PLAIN PLATE MATERIAL, HIGH STRENGTH LOW ALLOY STEEL

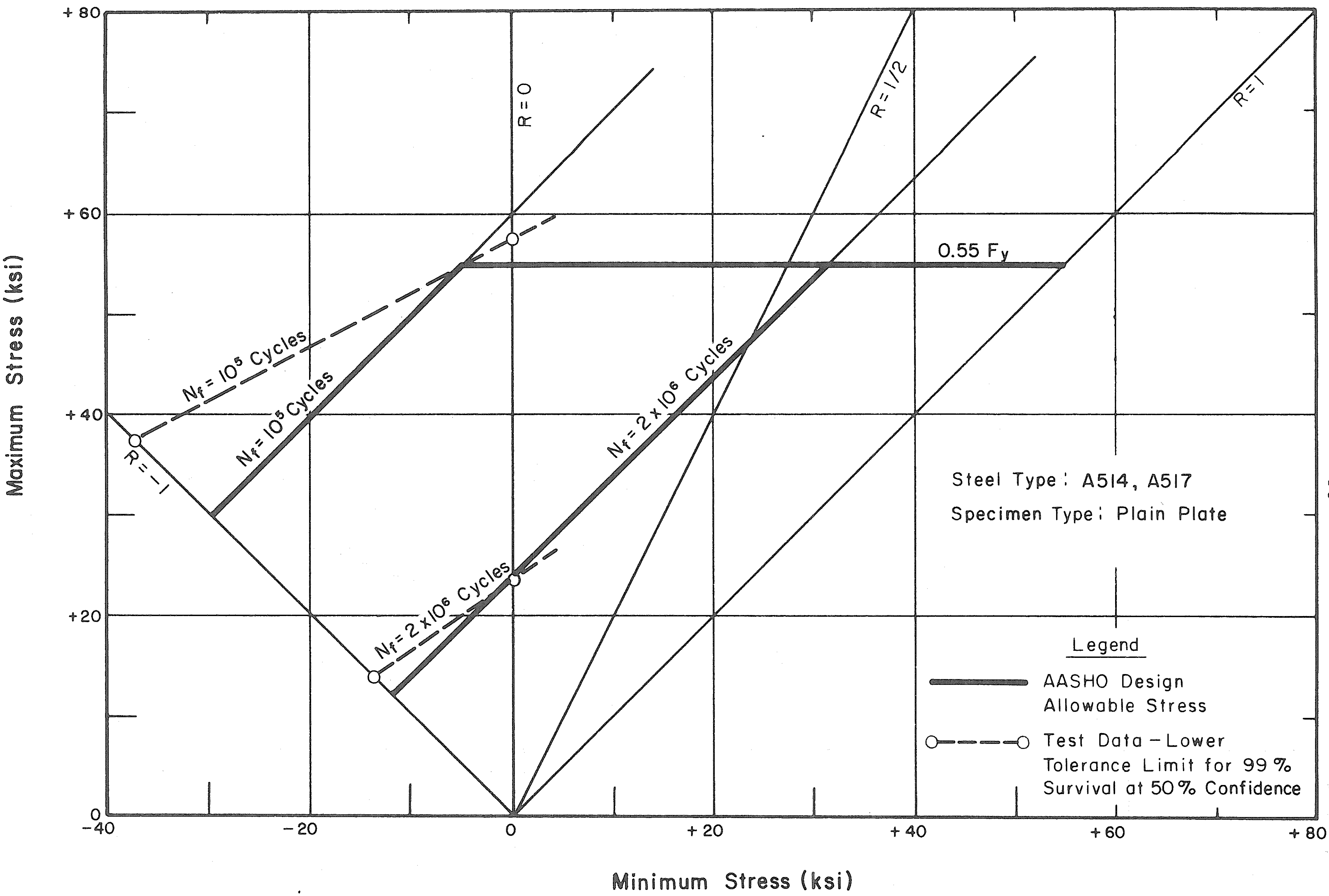


FIG. 4.3 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR PLAIN PLATE MATERIAL, HIGH YIELD STRENGTH QUENCHED AND TEMPERED ALLOY STEEL

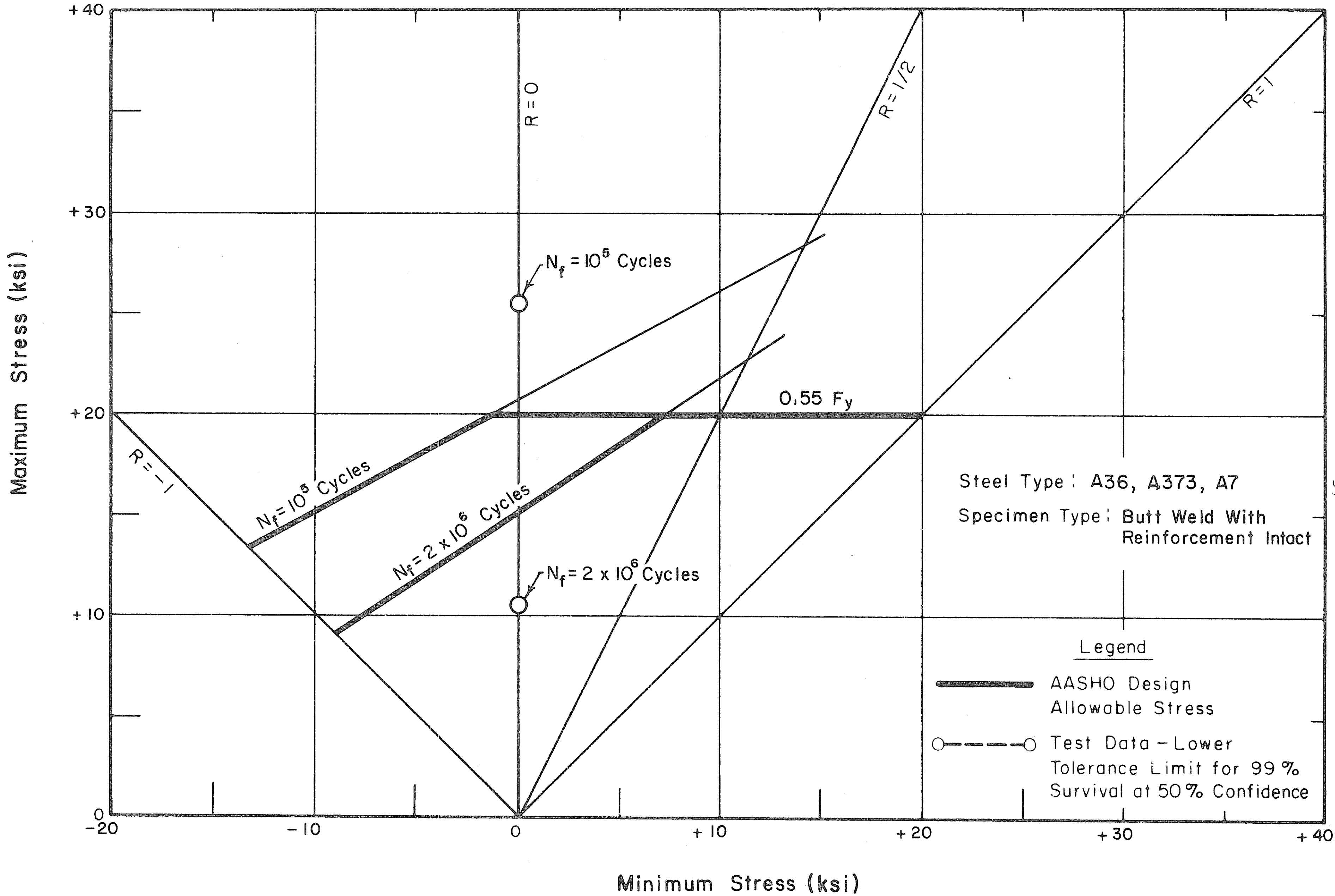


FIG. 4.4 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR BUTT WELD WITH REINFORCEMENT INTACT, STRUCTURAL CARBON STEEL

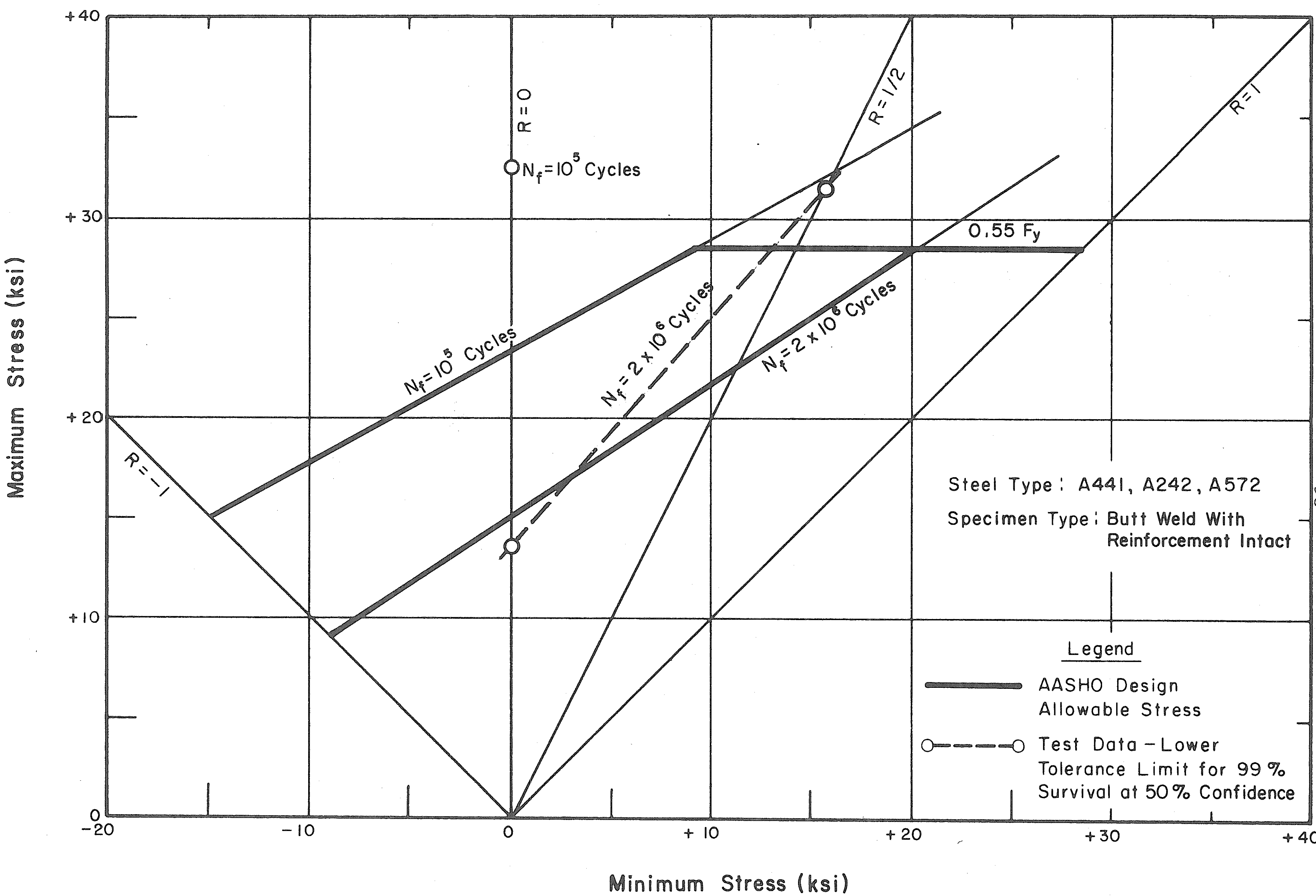


FIG. 4.5 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR BUTT WELD WITH REINFORCEMENT INTACT, HIGH STRENGTH LOW ALLOY STEEL

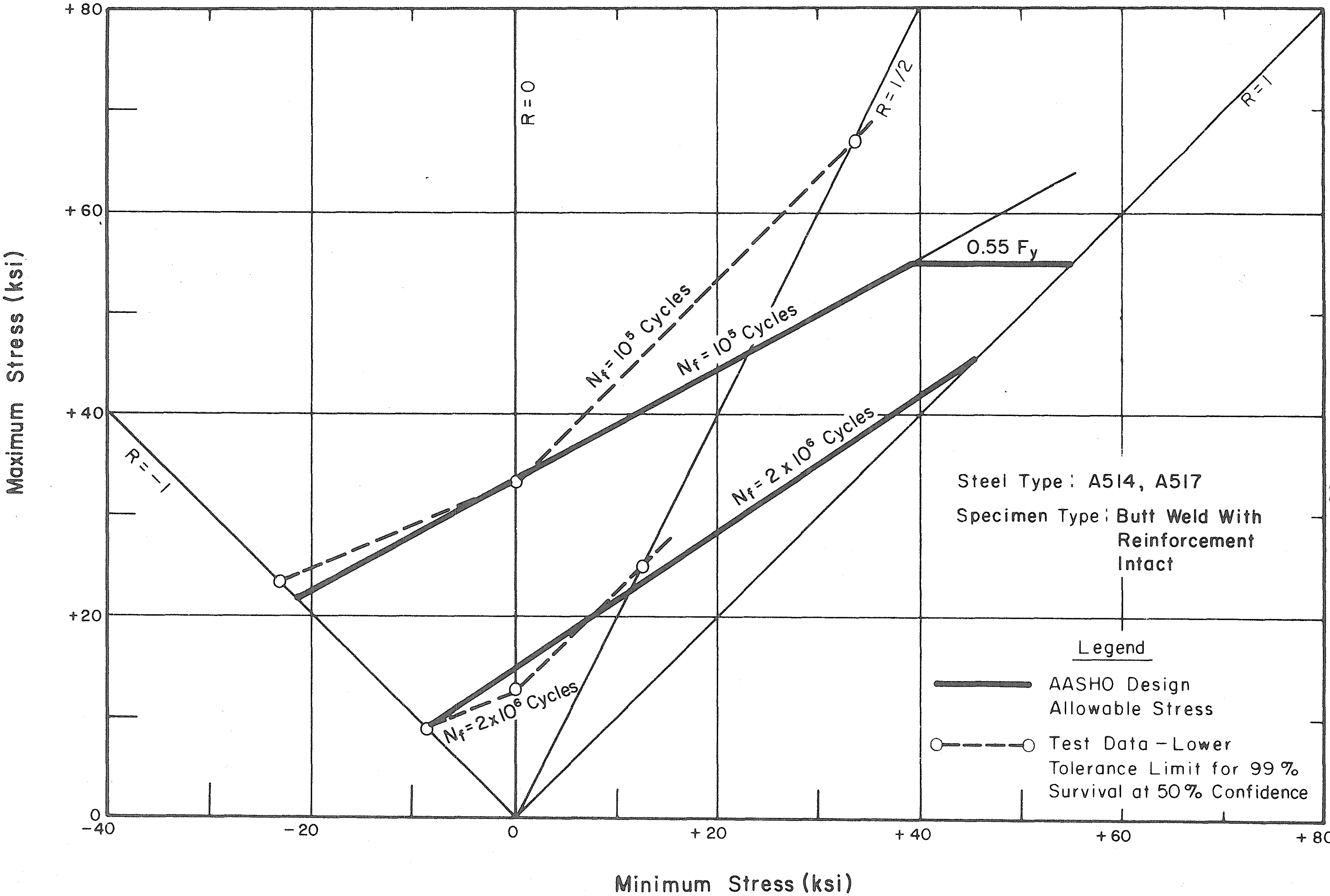


FIG. 4.6 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR BUTT WELD WITH REINFORCEMENT INTACT, HIGH YIELD STRENGTH QUENCHED AND TEMPERED ALLOY STEEL

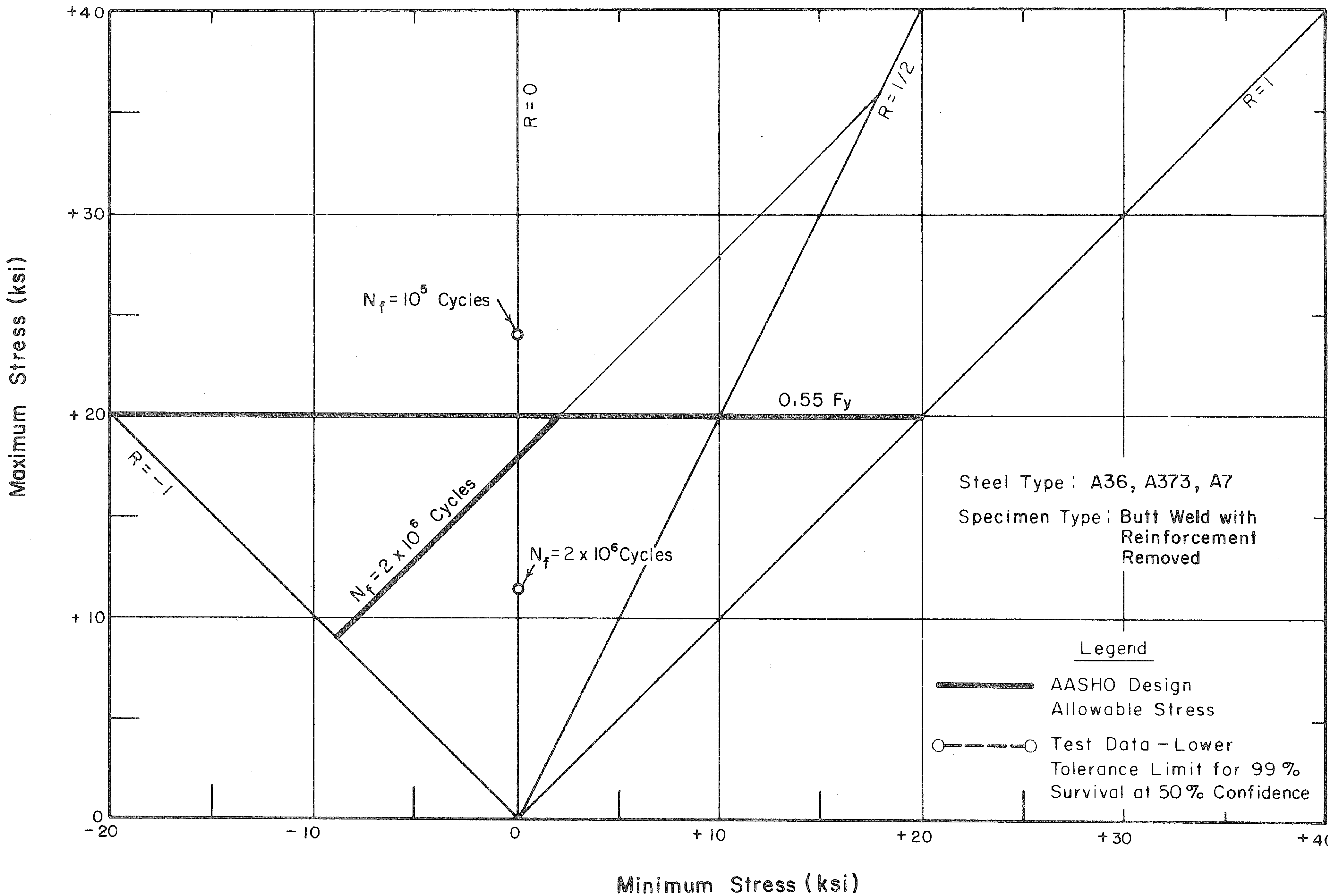


FIG. 4.7 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR BUTT WELD WITH REINFORCEMENT REMOVED, STRUCTURAL CARBON STEEL

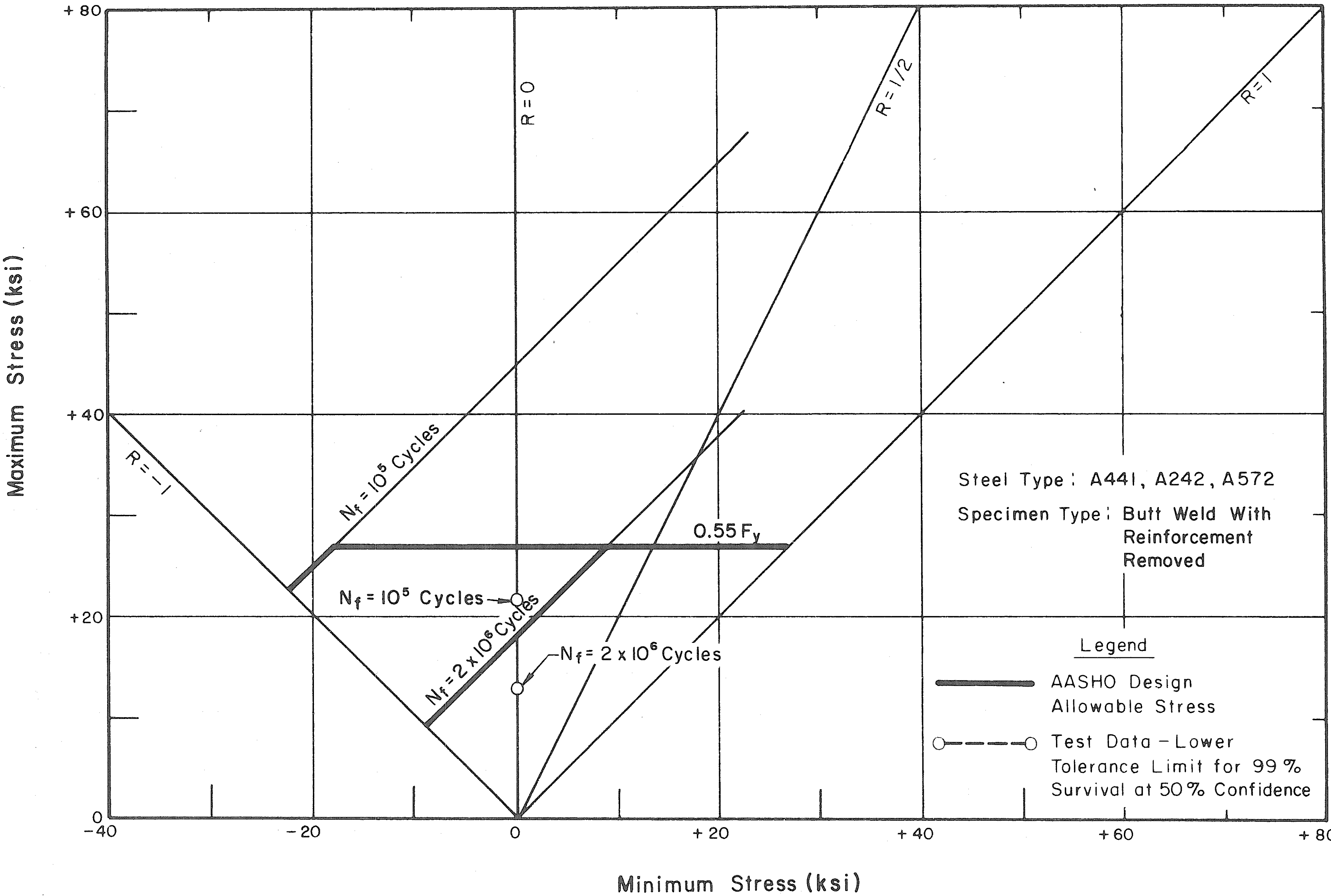


FIG. 4.8 FATIGUE DIAGRAM COMPARING TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR BUTT WELD WITH REINFOREMENT REMOVED, HIGH STRENGTH LOW ALLOY STEEL

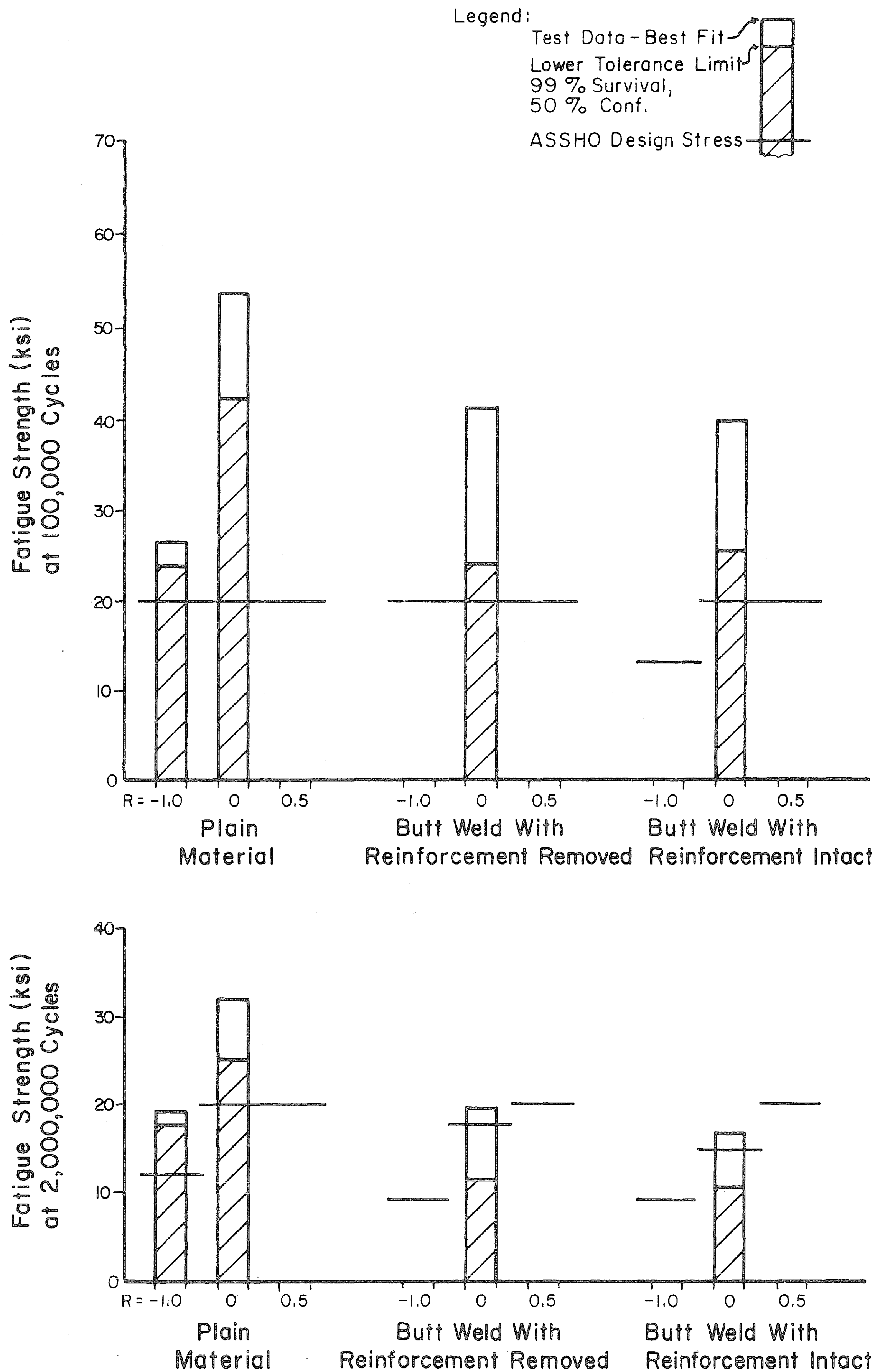


FIG. 4.9 COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR STRUCTURAL CARBON STEEL

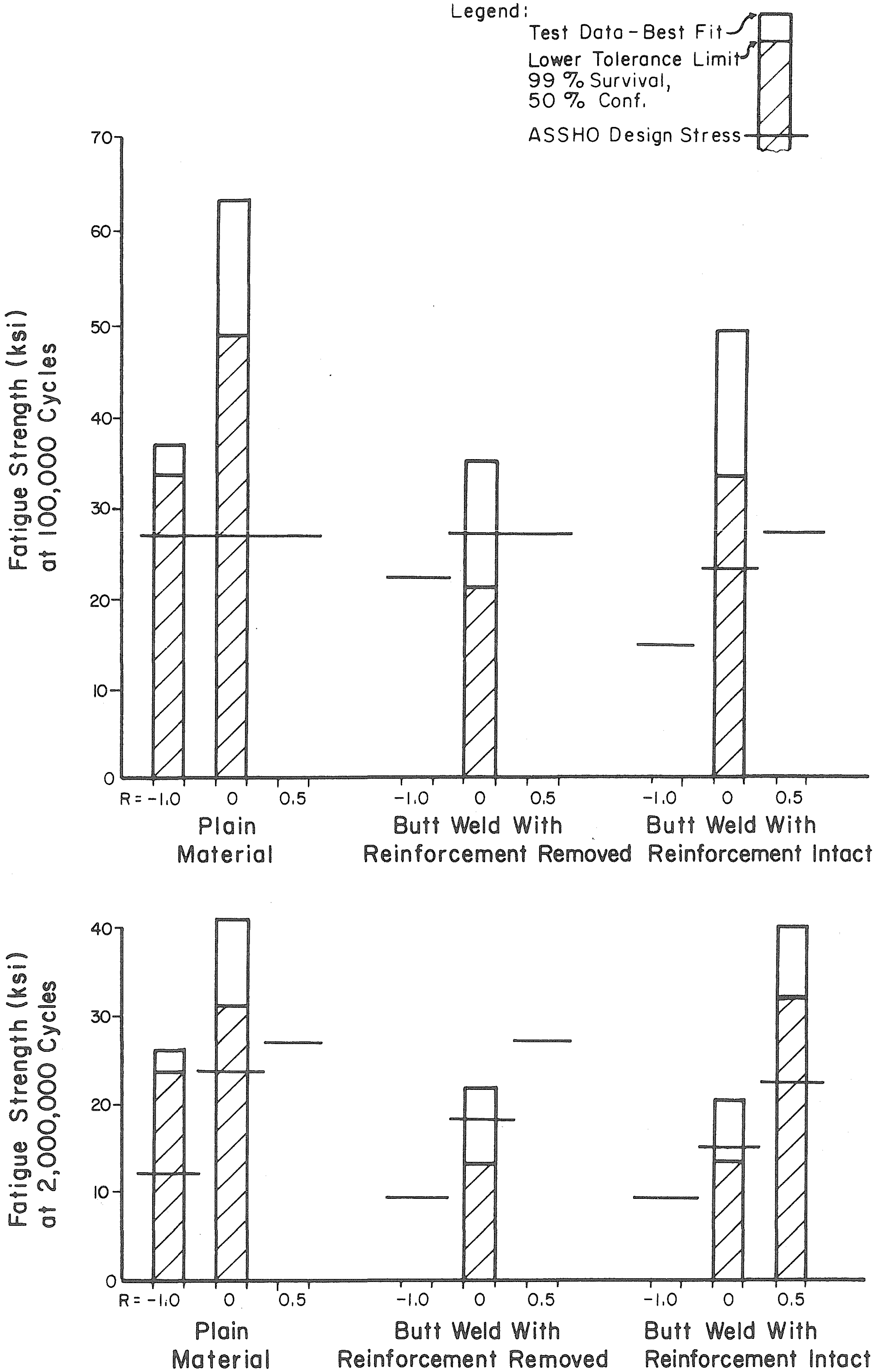


FIG. 4.10 COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR HIGH STRENGTH LOW ALLOY STEEL

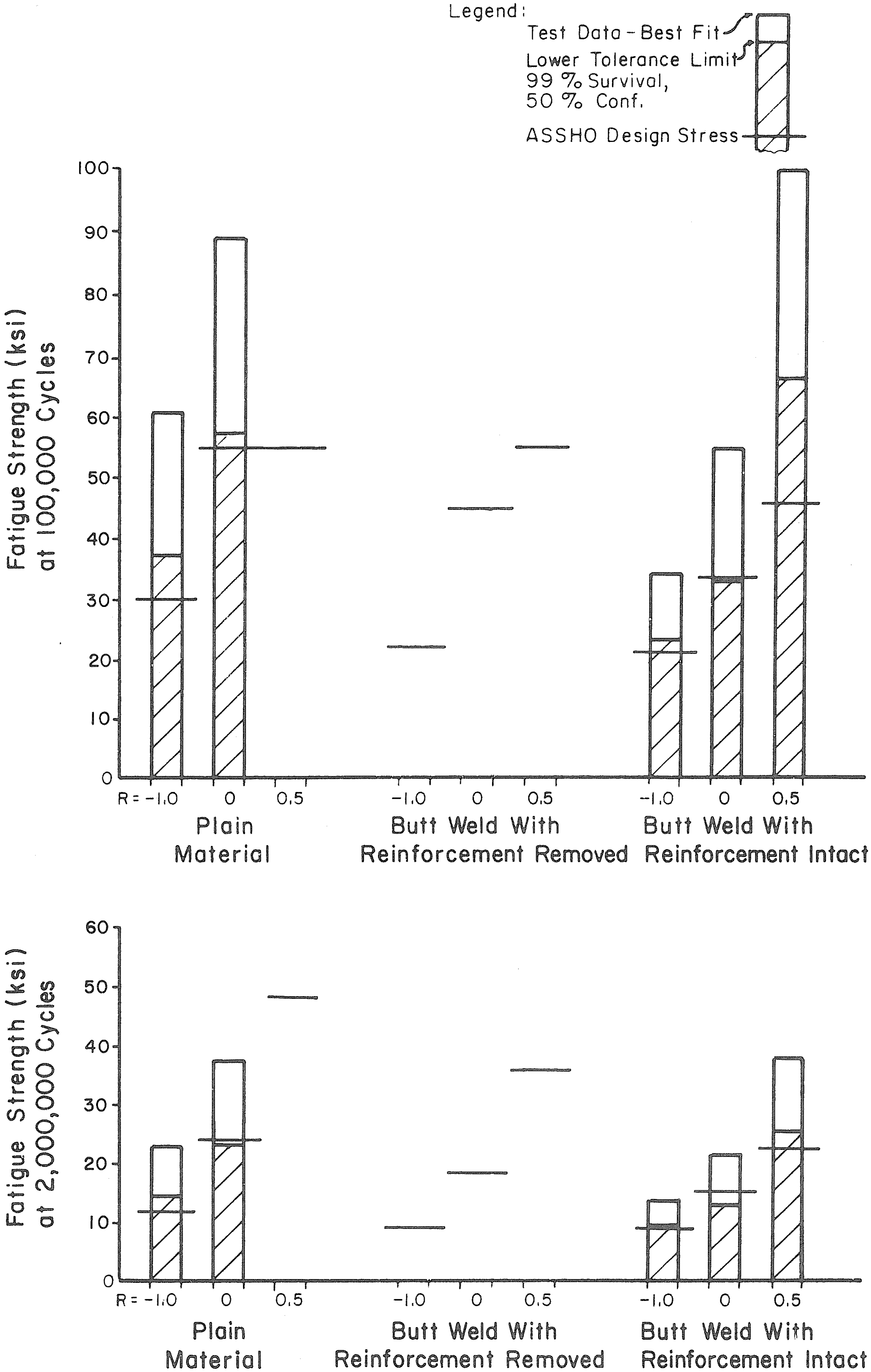


FIG. 4.11 COMPARISON OF FATIGUE TEST DATA WITH AASHO DESIGN SPECIFICATIONS FOR HIGH YIELD STRENGTH QUENCHED AND TEMPERED ALLOY STEEL

APPENDIX A

Glossary of Terms

Symbol	Definition
A	An empirical constant related to the fatigue behavior of a test specimen.
B	An empirical constant, the inverse of the slope of the linear log S_{max} vs. log N_f regression line.
E	Modulus of elasticity.
M_y	Applied bending moment corresponding to condition of first yielding at extreme fibers of cross-section of member loaded in flexure.
M_p	Applied bending moment corresponding to condition of full yielding over cross-section of member loaded in flexure.
N_f	The total number of applied cycles to fatigue failure.
P_y	Applied load corresponding to condition of yielding over cross-section of member loaded in axial tension.
R	Stress ratio; i.e., ratio of cyclic minimum stress to cyclic maximum stress.
S_{max}	The stress having the highest algebraic value in the stress cycle (tensile stress considered positive, compressive stress considered negative).
S_{min}	The stress having the lowest algebraic value in the stress cycle.

S_{mean}	The algebraic average of the maximum and minimum stress in one cycle; i.e., $(S_{max} + S_{min})/2$
S_{range}	The algebraic difference between the maximum and minimum stress in one cycle; i.e., $S_{max} - S_{min}$.
S_y	The yield strength of a material in uniaxial tension.
S_p	A "nominal" stress corresponding to a condition of full yielding over the cross-section of member subjected to pure bending; i.e., $S_y \cdot Z_p/Z_e$.
Z_e	Elastic section modulus of a member cross-section.
Z_p	Plastic section modulus of a member cross-section.
n	Number of specimens satisfying the required conditions for which an S-N curve is to be determined.
p	Percent survival for the lower tolerance limit at a specified confidence level.
γ	Confidence level specified for a particular lower tolerance limit.
r	Correlation coefficient.
s	Standard error of estimate.
x	Transformed fatigue life; i.e., log N_f.
y	Transformed cyclic maximum stress (or stress range); i.e., log S_{max} (or log S_{range}).

APPENDIX B

Formulation of Upper and Lower Limits to S-N Curve

Upper Limit to S-N Curve

For a member loaded axially the nominal yield strength is simply:

$$S_y = \frac{P_y}{Area} \tag{B1}$$

where P_y is the applied load necessary to produce yielding of the entire cross-section. This yield strength S_y is used as the upper limit for the cyclic maximum stress in determining the linear portion of the log S_{max} vs. log N_f regression line for members subjected to axial fatigue loadings.

For a similar member subjected to pure bending, the stress corresponding to the point of *first* yielding at the outermost fibers of the member cross-section is related to the externally applied moment, Fig. B1a, by:

$$S_y = \frac{M_y}{Z_e} \tag{B2}$$

where Z_e (elastic section modulus) is a geometrical property of the cross-section. Equation B2 reflects the assumption of a linear variation in stress from the neutral axis of the cross-section to its extreme fibers.

As the externally applied moment is increased beyond M_y, the stress at the extreme fibers of the cross-section remains essentially constant (if, as in the case of most structural grade steels, the material exhibits a reasonably flat stress-strain relationship beyond yield), while the stresses on the remaining section increase progressively until such time as yielding is approached across the entire section, Fig. B1b. At this stage, the yield strength of the material is related to the fully "plastic" moment capacity of the member, M_p, by:

$$S_y = \frac{M_p}{Z_p} \tag{B3}$$

where Z_p, the plastic section modulus, is a geometrical property of the member cross-section which relates M_p to S_y through the assumption of a rectangular stress block, Fig. B1b, acting on the member section. The ratios of plastic modulus to elastic modulus for three common cross-sections are:

rectangular cross-section	$Z_p/Z_e = 1.5$
circular cross-section	$Z_p/Z_e = 1.7$
I or wide-flange section	$1.1 \leq Z_p/Z_e \leq 1.2$ approx.

By equating relationships (B2) and (B3) above, the moment required to produce full yielding over the member section is related to the moment at first yielding by:

$$M_p = M_y \cdot \frac{Z_p}{Z_e} \tag{B4}$$

A maximum "nominal" stress, S_p (a computed value used to represent a numerical, though non-existent, stress by using an elastic section modulus for conditions of loading beyond the elastic range) corresponding to the external moment M_p, may now be defined as follows:

$$S_p = \frac{M_p}{Z_e} = \frac{M_y}{Z_e} \cdot \frac{Z_p}{Z_e}$$

or

$$S_p = S_y \cdot \frac{Z_p}{Z_e} \tag{B5}$$

For example, for a member of rectangular cross-section, the maximum "nominal" stress corresponding to full nominal yielding of the section under flexure would be:

$$S_p = 1.5\, S_y \quad \text{(rectangular section)}$$

This "nominal" or "pseudo" stress, S_p, Equation B5, is the value taken by the computer as the upper limit of the linear logarithmic S-N regression line for data obtained from flexural tests of structural members and details. The justification for using S_p as the upper limit rather than the actual material yield strength, S_y, as in axial fatigue tests, is simply that there is evidence that such a straight line extrapolation of the S-N curve to this limit appears to describe flexural test data quite well in the low cycle fatigue region.

Lower Limit to S-N Curve

It has been observed, from numerous fatigue tests of structural steel members and components, that the S-N curve representative of the fatigue data changes slope and often becomes essentially horizontal at approximately 2×10^6 cycles.[6] In a first, or trial, analysis of an individual set of fatigue data, the computer program developed for this study also assumes a lower limit of 2×10^6 cycles for the calculated linear logarithmic S-N regression line described in Section III. The procedure used in considering specimens having lives beyond two million cycles is outlined in the following paragraphs.

As the first step in the analytical process, a trial S-N curve is obtained as follows. The specimen fatigue lives from all "run-out" tests and tests in which failure occurred after 2×10^6 cycles are projected horizontally to two million cycles. An S-N regression line is then generated using these adjusted lives together with the actual data for specimens exhibiting failure at lives less than 2×10^6 cycles. For this life, the fatigue strength and standard error of estimate at 2×10^6 cycles are computed. Next a "limit of acceptance" for the run-out test data is established (as a specified multiple of -1 x standard error of estimate), which is then projected as a horizontal line parallel to the line corresponding to the computed fatigue strength at 2×10^6 cycles (see Fig. B2). Then, for a second trial, any run-out test data residing below the lower acceptance line is rejected while all other data points are again included in the second analysis. A new S-N curve is constructed and the above process repeated until no additional test points are rejected. It may be noted that, in establishing the fatigue strength at 2,000,000 cycles, this process is essentially a conservative one, in that the long life fatigue strengths so computed will generally be lower than the strengths computed using data only for specimens exhibiting failure at less than 2×10^6 cycles.

As noted above, the breaking point of the log S vs. log N_f curve was chosen arbitrarily at two million cycles on the basis of past observations. However, this assumed behavior may not be particularly representative for all data. Therefore, if, upon subsequent examination of the plotted data and S-N curve for a particular series of tests, it appears that the breaking point occurs at some other life, say 3×10^6 cycles, the computer program can be run again using the new lifetime as the lower limit for the S-N regression line. The process of run-out data acceptance or rejection can then be repeated as explained in the preceding paragraph until a final S-N curve is established.

The program has a third option in this regard which assumes no flattening out of the S-N curve at long fatigue lives. If this option is specified, a single best-fit linear regression line is generated using all data for specimens actually exhibiting failures (i.e., tests not carried to failure are rejected) regardless of whether or not the lives were beyond two million cycles. This alternative has been made available for those tests in which it appears that no tendency toward a horizontal asymptote of the S-N curve can be distinguished from examination of the plotted data points.

It is anticipated that the flexibility of the computational process indicated by the three options outlined above will be sufficient to enable adequate analytical description of the fatigue behavior of the vast majority of structural members and details. In cases where it may be difficult to decide which of the alternatives offers the best representation of a particular data set, examination of the correlation coefficient corresponding to each of the alternatives should be helpful in a final assessment.

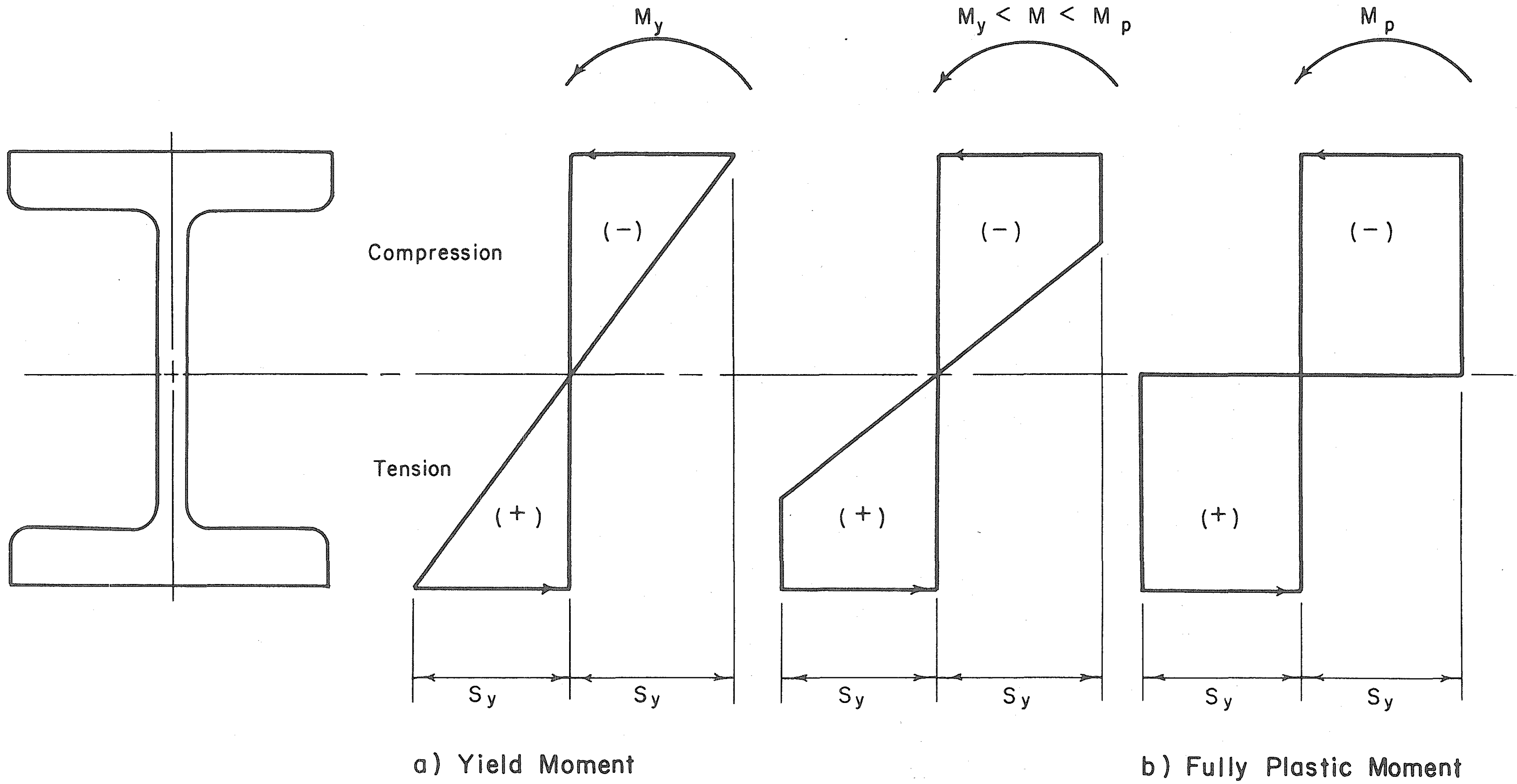


FIG. B1 PROGRESSIVE STATES OF STRESS FOR MEMBER SUBJECTED TO FLEXURAL LOADING

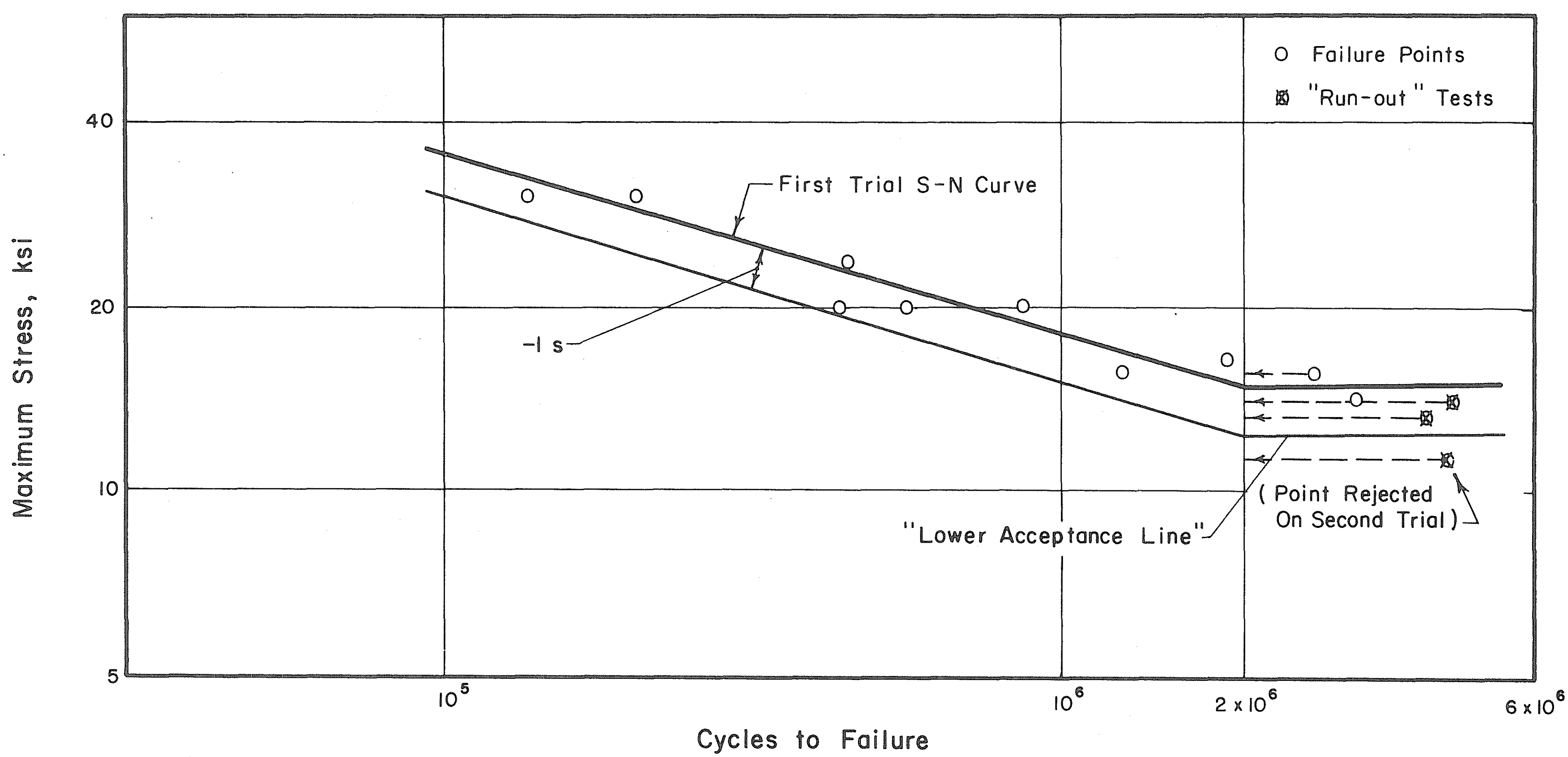


FIG. B2 ILLUSTRATION OF PROCEDURE FOR CONSIDERING "RUN-OUT" TEST DATA IN REGRESSION ANALYSIS

APPENDIX C

COMPUTER PRINTOUT OF FATIGUE ANALYSIS RESULTS

SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 1

STEEL TYPE = A7,A36,A373,MILD STEEL

STRESS CYCLE = COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 13

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 24.34106 B =-9.68221

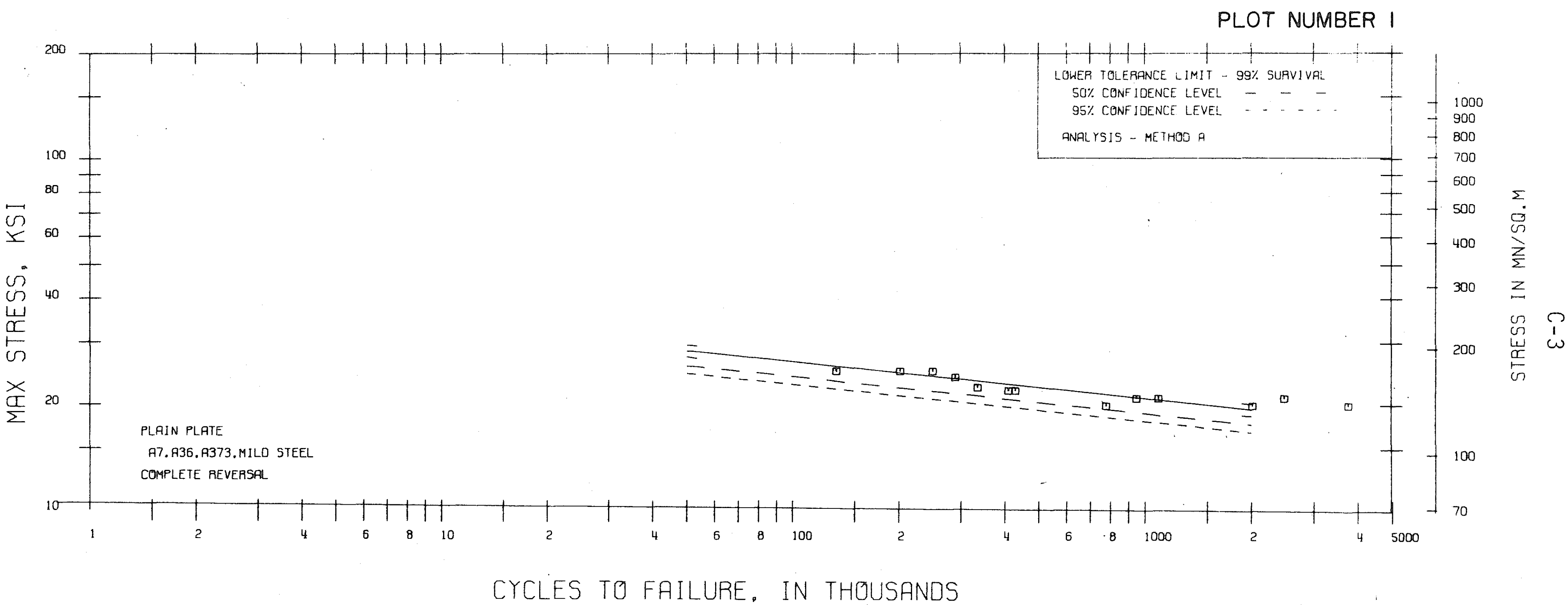
STANDARD ERROR OF ESTIMATE = 0.67642

CORRELATION COEFFICIENT = 0.90731

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.10328

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(50000) = 28.5 KSI	27.3 KSI	25.8 KSI	24.6 KSI
F(100000) = 26.5	25.4	24.1	22.9
F(200000) = 24.7	23.7	22.4	21.3
F(500000) = 22.4	21.5	20.4	19.4
F(1 MILL) = 20.9	20.1	19.0	18.0
F(2 MILL) = 19.4	18.7	17.7	16.8
F(50000) = 196.2 MN/SQ.M	188.4 MN/SQ.M	178.2 MN/SQ.M	169.3 MN/SQ.M
F(100000) = 182.6	175.4	165.9	157.6
F(200000) = 170.0	163.3	154.4	146.7
F(500000) = 154.7	148.6	140.5	133.5
F(1 MILL) = 144.0	138.3	130.8	124.3
F(2 MILL) = 134.0	128.7	121.7	115.7


PLOT NUMBER I
LOWER TOLERANCE LIMIT - 99% SURVIVAL
50% CONFIDENCE LEVEL
95% CONFIDENCE LEVEL
ANALYSIS - METHOD A
PLAIN PLATE
A7.A36.A373.MILD STEEL
COMPLETE REVERSAL
MAX STRESS, KSI
STRESS IN MN/SQ.M
CYCLES TO FAILURE, IN THOUSANDS
200
100
80
60
40
20
10
1000
900
800
700
600
500
400
300
200
100
70
1
2
4
6
8
10
2
4
6
8
100
2
4
6
8
1000
2
4
5000

SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 2

STEEL TYPE = A7,A36,A373,MILD STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 51

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 24.85370 B =-5.76218

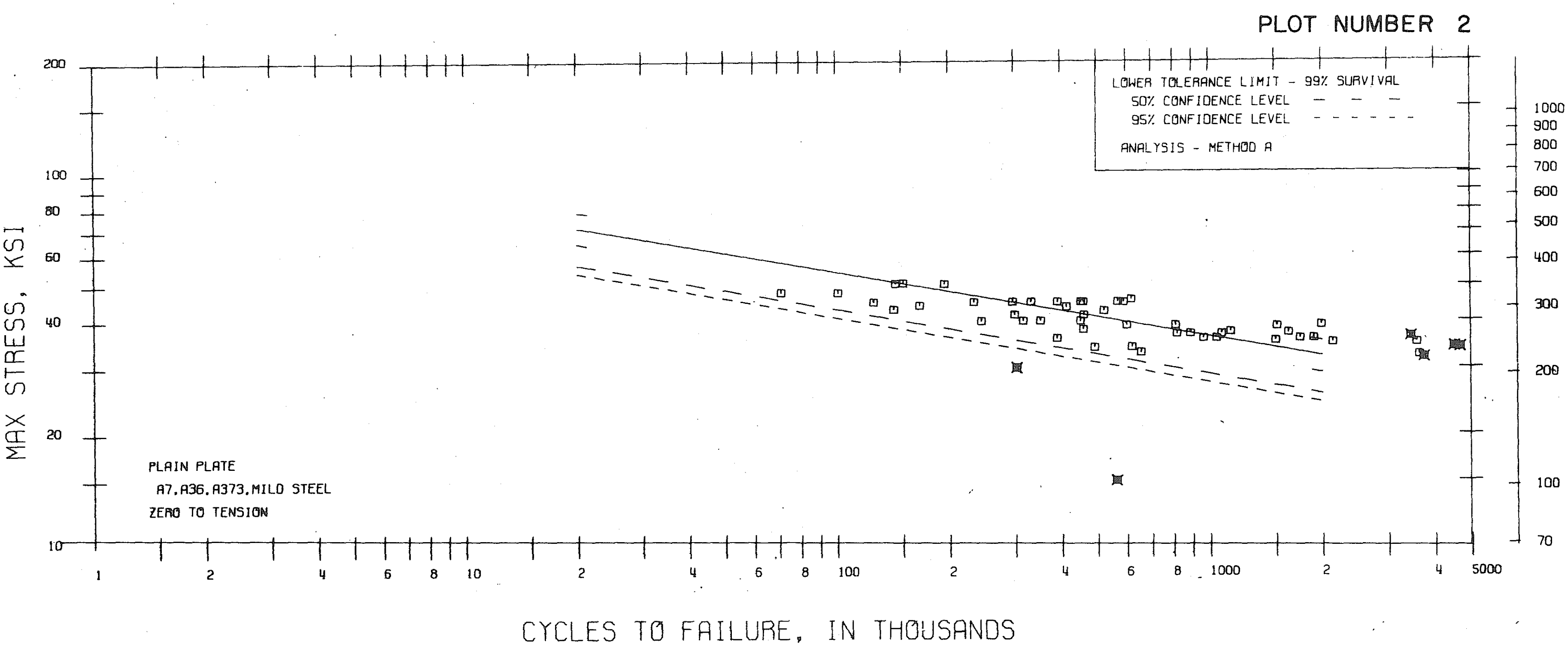
STANDARD ERROR OF ESTIMATE = 0.98422

CORRELATION COEFFICIENT = 0.78622

ABSOLUTE VALUE OF SLOPE
OF S-N CURVE = 0.17355

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(20000) = 71.4 KSI	64.7 KSI	56.7 KSI	53.9 KSI
F(50000) = 60.9	55.2	48.4	46.0
F(100000) = 54.0	49.0	42.9	40.8
F(200000) = 47.9	43.4	38.1	36.2
F(500000) = 40.9	37.0	32.5	30.9
F(1 MILL) = 36.2	32.8	28.8	27.4
F(2 MILL) = 32.1	29.1	25.5	24.3
F(20000) = 492.6 MN/SQ.M	446.4 MN/SQ.M	391.2 MN/SQ.M	371.9 MN/SQ.M
F(50000) = 420.1	380.8	333.7	317.2
F(100000) = 372.5	337.6	295.9	281.3
F(200000) = 330.3	299.3	262.3	249.4
F(500000) = 281.7	255.3	223.8	212.7
F(1 MILL) = 249.8	226.4	198.4	188.6
F(2 MILL) = 221.5	200.7	175.9	167.2


PLOT NUMBER 2
LOWER TOLERANCE LIMIT - 99% SURVIVAL
50% CONFIDENCE LEVEL
95% CONFIDENCE LEVEL
ANALYSIS - METHOD A
MAX STRESS, KSI
STRESS IN MN/SQ.M
CYCLES TO FAILURE, IN THOUSANDS
PLAIN PLATE
A7,A36,A373,MILD STEEL
ZERO TO TENSION
200
100
80
60
40
20
10
1000
900
800
700
600
500
400
300
200
100
70
1
2
4
6
8
10
2
4
6
8
100
2
4
6
8
1000
2
4
5000

SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 3

STEEL TYPE =A242,A441,HIGH STRENGTH LOW ALLOY STEEL

STRESS CYCLE = COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 10

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 27.77150 B =-8.70795

STANDARD ERROR OF ESTIMATE = 0.55721

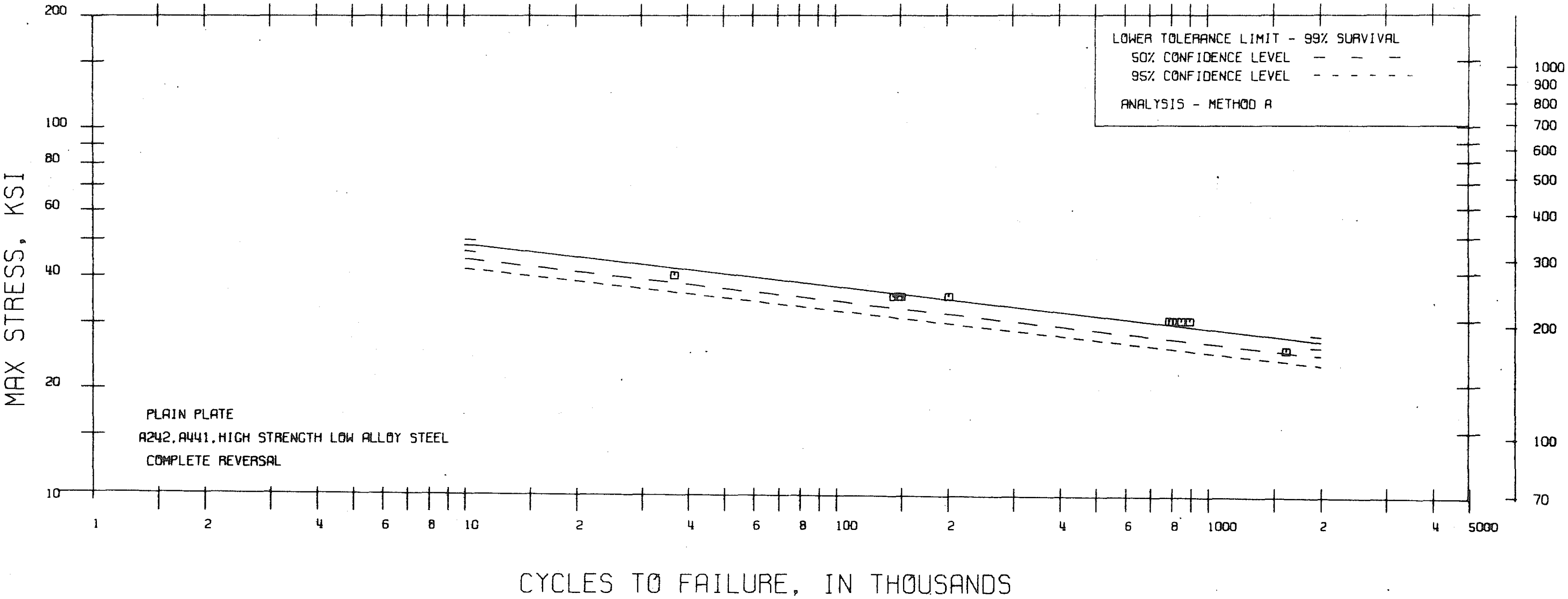
CORRELATION COEFFICIENT = 0.96362

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.11484

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(10000) = 48.3 KSI	46.5 KSI	44.2 KSI	41.7 KSI
F(20000) = 44.6	43.0	40.8	38.5
F(50000) = 40.1	38.7	36.7	34.6
F(100000) = 37.1	35.7	33.9	32.0
F(200000) = 34.2	33.0	31.3	29.5
F(500000) = 30.8	29.7	28.2	26.6
F(1 MILL) = 28.4	27.4	26.0	24.6
F(2 MILL) = 26.3	25.3	24.0	22.7
F(10000) = 332.8 MN/SQ.M	320.8 MN/SQ.M	304.5 MN/SQ.M	287.4 MN/SQ.M
F(20000) = 307.4	296.2	281.2	265.4
F(50000) = 276.7	266.6	253.1	238.9
F(100000) = 255.5	246.2	233.8	220.6
F(200000) = 235.9	227.4	215.9	203.7
F(500000) = 212.4	204.7	194.3	183.4
F(1 MILL) = 196.1	189.0	179.5	169.4
F(2 MILL) = 181.1	174.6	165.7	156.4

PLOT NUMBER 3



SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 4

STEEL TYPE =A242,A441,HIGH STRENGTH LOW ALLOY STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 27

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 29.52837 B =-6.71386

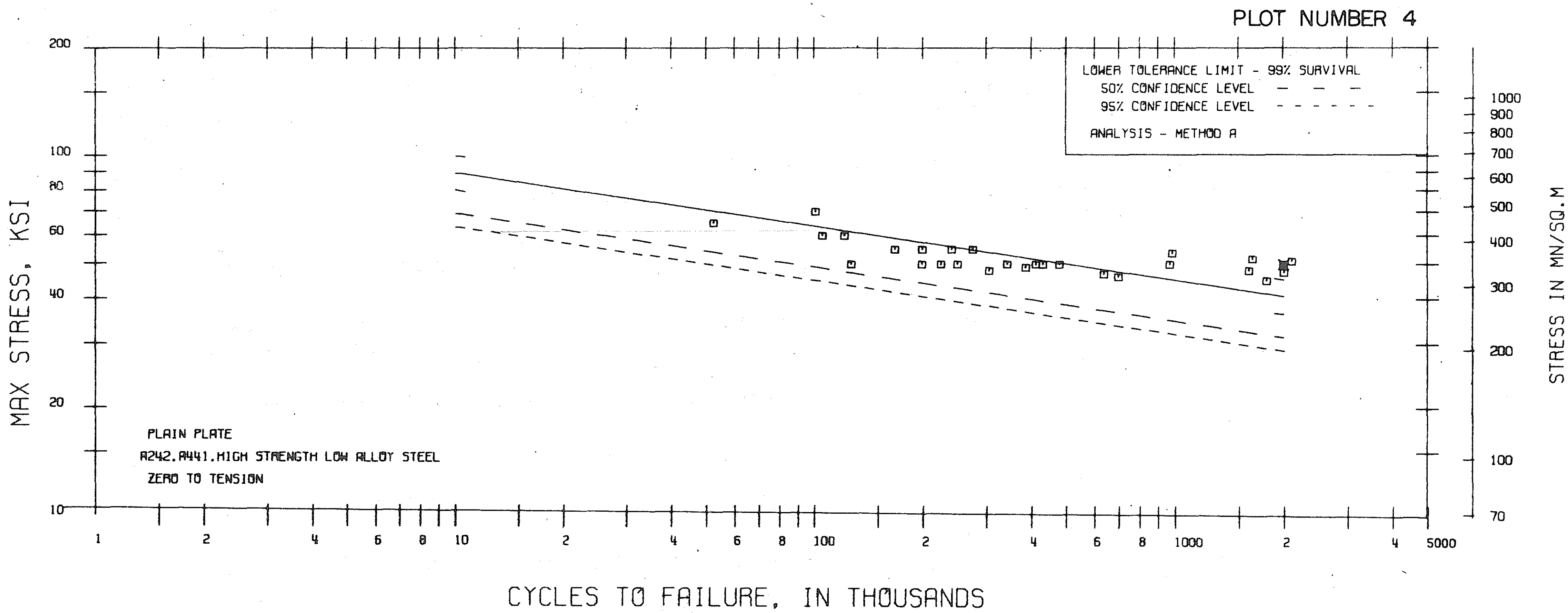
STANDARD ERROR OF ESTIMATE = 1.28938

CORRELATION COEFFICIENT = 0.68197

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.14895

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 95% CONFIDENCE
F(10000) = 89.5 KSI	80.2 KSI	69.0 KSI	63.4 KSI
F(20000) = 80.8	72.3	62.2	57.2
F(50000) = 70.5	63.1	54.3	49.9
F(100000) = 63.5	56.9	49.0	45.0
F(200000) = 57.3	51.3	44.2	40.6
F(500000) = 50.0	44.8	38.5	35.4
F(1 MILL) = 45.1	40.4	34.8	31.9
F(2 MILL) = 40.7	36.4	31.3	28.8
F(10000) = 617.3 MN/SQ.M	552.7 MN/SQ.M	475.8 MN/SQ.M	437.3 MN/SQ.M
F(20000) = 556.8	498.5	429.1	394.4
F(50000) = 485.8	434.9	374.3	344.1
F(100000) = 438.1	392.2	337.6	310.4
F(200000) = 395.1	353.8	304.5	279.9
F(500000) = 344.7	308.6	265.7	244.2
F(1 MILL) = 310.9	278.4	239.6	220.3
F(2 MILL) = 280.4	251.0	216.1	198.7



PLOT NUMBER 4
LOWER TOLERANCE LIMIT - 99% SURVIVAL
50% CONFIDENCE LEVEL
95% CONFIDENCE LEVEL
ANALYSIS - METHOD A
PLAIN PLATE
A242.A441.HIGH STRENGTH LOW ALLOY STEEL
ZERO TO TENSION
MAX STRESS, KSI
STRESS IN MN/SQ.M
CYCLES TO FAILURE, IN THOUSANDS

SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 5

STEEL TYPE =A514,A517,HIGH STRENGTH Q & T STEEL

STRESS CYCLE =COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 32

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 17.34129 B =-2.95280

STANDARD ERROR OF ESTIMATE = 1.14353

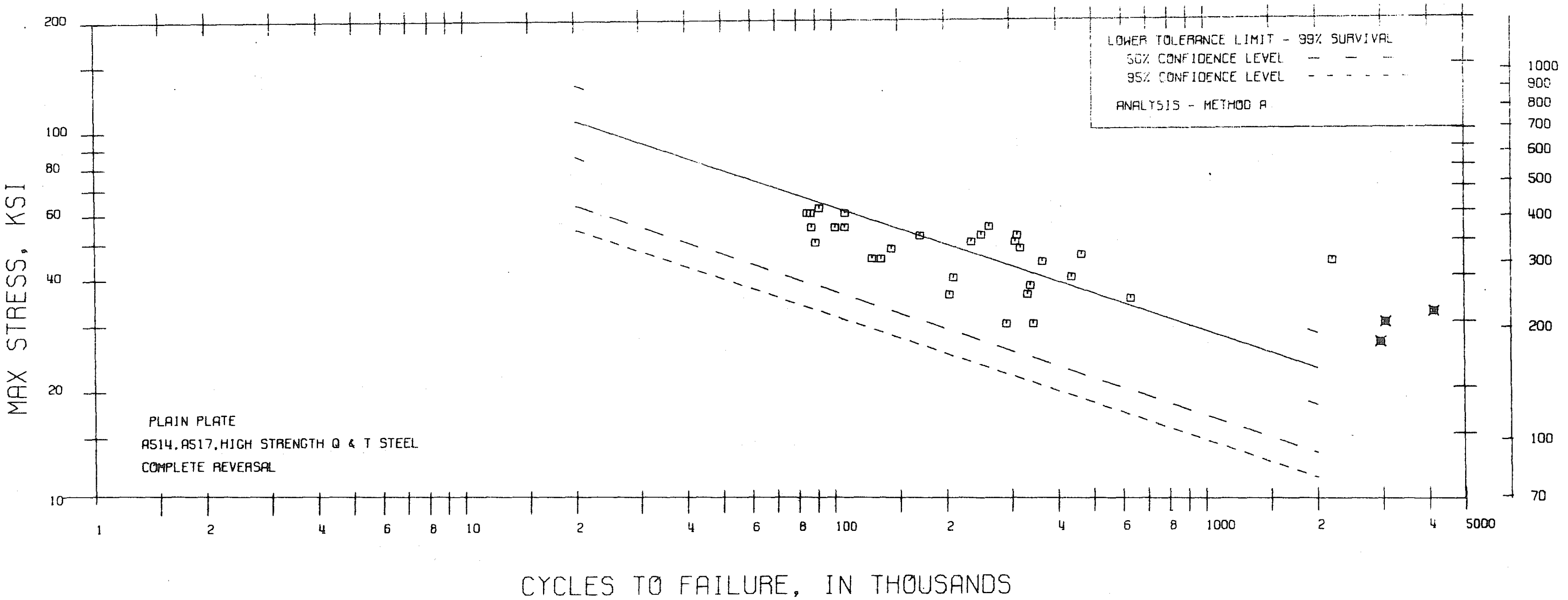
CORRELATION COEFFICIENT = 0.72639

ABSOLUTE VALUE OF SLOPE
OF S-N CURVE = 0.33866

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

		LOWER TOLERANCE LIMITS FOR 99% SURVIVAL	
FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	50% CONFIDENCE	95% CONFIDENCE
F(20000) =107.0 KSI	85.6 KSI	63.3 KSI	54.4 KSI
F(50000) = 78.4	62.8	46.4	39.9
F(100000) = 62.0	49.6	36.7	31.5
F(200000) = 49.0	39.2	29.0	24.9
F(500000) = 36.0	28.8	21.3	18.3
F(1 MILL) = 28.4	22.8	16.8	14.5
F(2 MILL) = 22.5	18.0	13.3	11.4
F(20000) = 737.6 MN/SQ.M	590.1 MN/SQ.M	436.6 MN/SQ.M	374.8 MN/SQ.M
F(50000) = 540.8	432.7	320.1	274.8
F(100000) = 427.6	342.1	253.2	217.3
F(200000) = 338.2	270.6	200.2	171.9
F(500000) = 247.9	198.4	146.8	126.0
F(1 MILL) = 196.1	156.9	116.1	99.6
F(2 MILL) = 155.0	124.0	91.8	78.8

PLOT NUMBER 5



SPECIMEN TYPE = PLAIN PLATE

PLOT NUMBER 6

STEEL TYPE =A514,A517,HIGH YIELD STRENGTH Q&T STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 115

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 20.95959 B =-3.39769

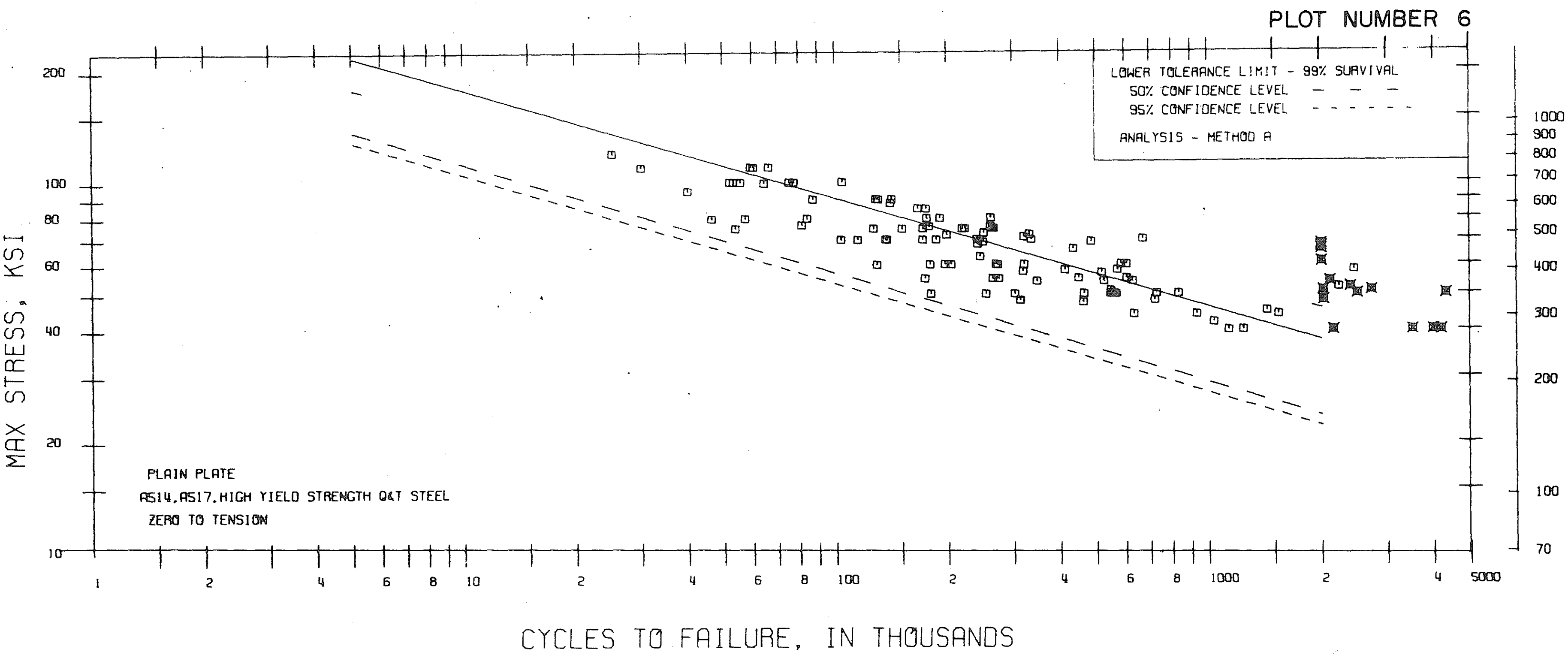
STANDARD ERROR OF ESTIMATE = 1.16980

CORRELATION COEFFICIENT = 0.80628

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.29432

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(5000) =217.9 KSI	178.7 KSI	137.2 KSI	128.6 KSI
F(10000) =177.7	145.7	111.9	104.9
F(20000) =144.9	118.8	91.2	85.5
F(50000) =110.6	90.7	69.7	65.3
F(100000) = 90.2	74.0	56.8	53.3
F(200000) = 73.6	60.3	46.3	43.4
F(500000) = 56.2	46.1	35.4	33.2
F(1 MILL) = 45.8	37.6	28.8	27.0
F(2 MILL) = 37.4	30.6	23.5	22.1
F(5000) =1502.2 MN/SQ.M	1231.9 MN/SQ.M	945.7 MN/SQ.M	886.9 MN/SQ.M
F(10000) =1225.0	1004.6	771.2	723.2
F(20000) = 998.9	819.2	628.9	589.8
F(50000) = 762.8	625.6	480.2	450.3
F(100000) = 622.0	510.1	391.6	367.2
F(200000) = 507.2	416.0	319.3	299.5
F(500000) = 387.3	317.7	243.9	228.7
F(1 MILL) = 315.9	259.0	198.9	186.5
F(2 MILL) = 257.6	211.2	162.2	152.1


PLOT NUMBER 6
LOWER TOLERANCE LIMIT - 99% SURVIVAL
50% CONFIDENCE LEVEL
95% CONFIDENCE LEVEL
ANALYSIS - METHOD A
PLAIN PLATE
A514,A517,HIGH YIELD STRENGTH Q&T STEEL
ZERO TO TENSION
MAX STRESS, KSI
STRESS IN MN/SQ.M
CYCLES TO FAILURE, IN THOUSANDS

PLOT NUMBER 7

SPECIMEN TYPE = PLAIN PLATE

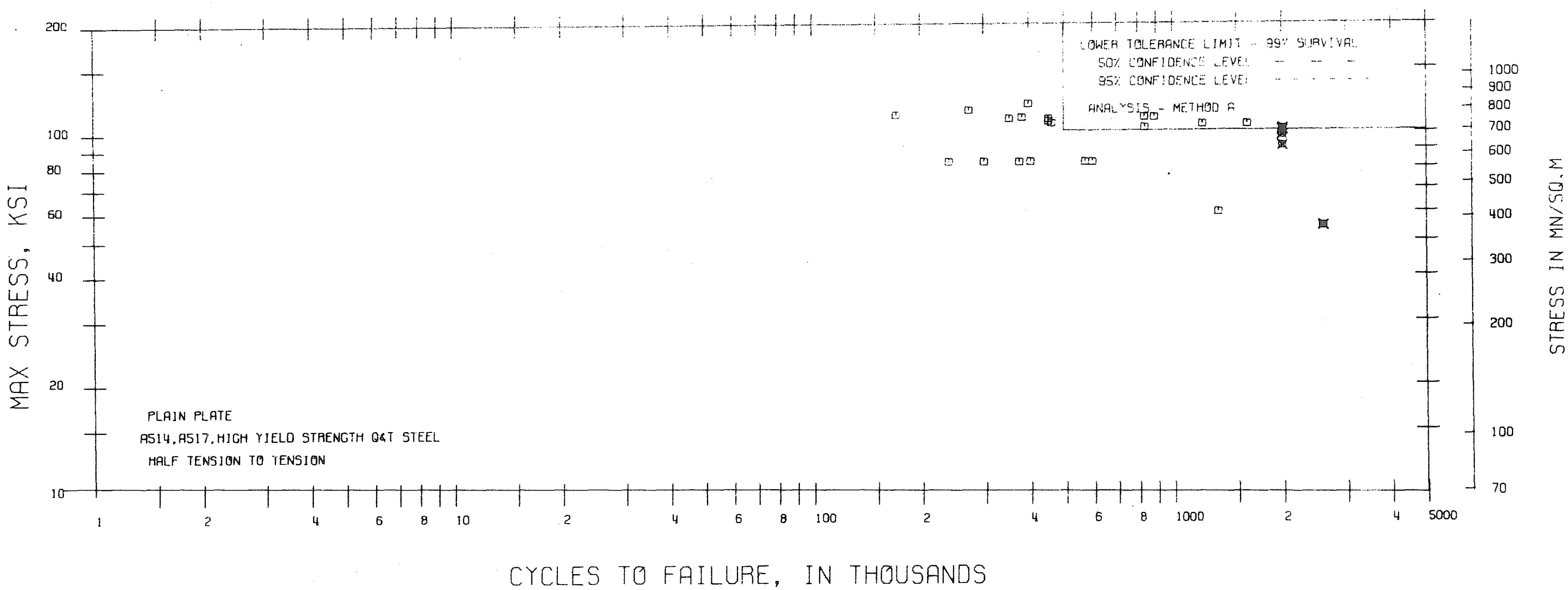
STEEL TYPE = A514, A517, HIGH YIELD STRENGTH Q + T STEEL

STRESS CYCLE = HALF TENSION TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

"DATA INADEQUATE FOR GENERATION OF S-N CURVE"

PLOT NUMBER 7



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT

PLOT NUMBER 8

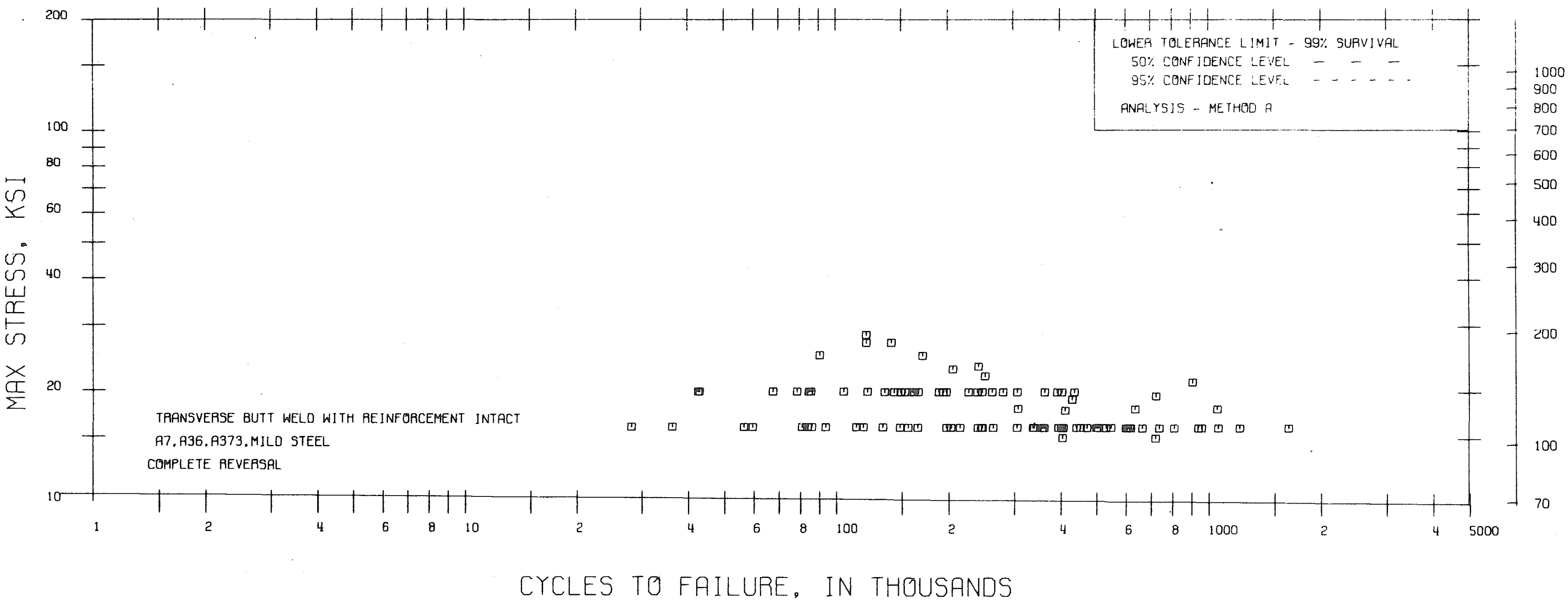
STEEL TYPE = A7, A36, A373, MILD STEEL

STRESS CYCLE = COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

DATA INADEQUATE FOR GENERATION OF S-N CURVE

PLOT NUMBER 8



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT

PLOT NUMBER 9

STEEL TYPE = A7,A373,MILD STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 123

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 16.33356 B =-3.45225

STANDARD ERROR OF ESTIMATE = 1.15418

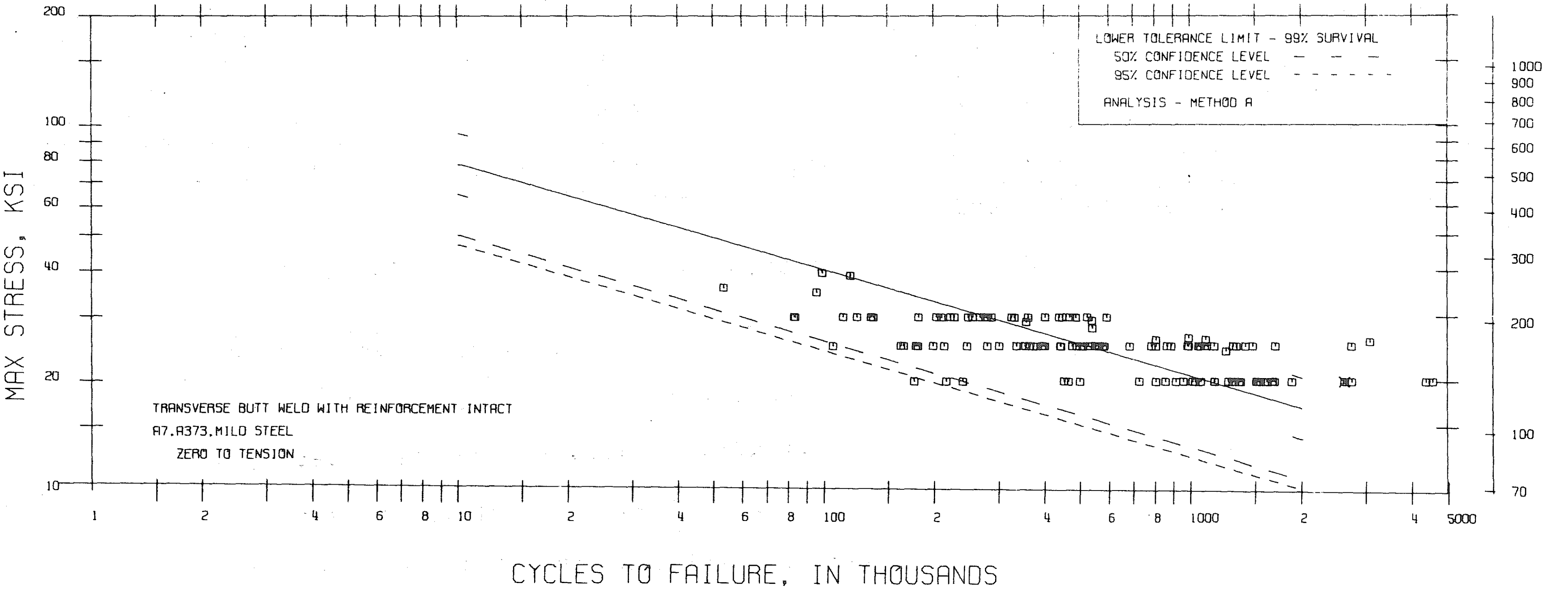
CORRELATION COEFFICIENT = 0.64458

ABSOLUTE VALUE OF SLOPE
OF S-N CURVE = 0.28967

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 90% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(10000) = 78.5 KSI	64.7 KSI	50.1 KSI	47.1 KSI
F(20000) = 64.2	52.9	41.0	38.6
F(50000) = 49.2	40.6	31.4	29.6
F(100000) = 40.3	33.2	25.7	24.2
F(200000) = 32.9	27.2	21.0	19.8
F(500000) = 25.3	20.8	16.1	15.2
F(1 MILL) = 20.7	17.0	13.2	12.4
F(2 MILL) = 16.9	13.9	10.8	10.2
F(10000) = 540.9 MN/SQ.M	446.2 MN/SQ.M	345.2 MN/SQ.M	325.0 MN/SQ.M
F(20000) = 442.5	365.0	282.4	265.9
F(50000) = 339.4	279.9	216.6	203.9
F(100000) = 277.6	229.0	177.2	166.8
F(200000) = 227.1	187.3	145.0	136.5
F(500000) = 174.2	143.7	111.2	104.7
F(1 MILL) = 142.5	117.5	90.9	85.6
F(2 MILL) = 116.6	96.2	74.4	70.0

PLOT NUMBER 9



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT

STEEL TYPE =A242,A572,HIGH STRENGTH LOW ALLOY STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 34

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 17.51518 B =-3.41863

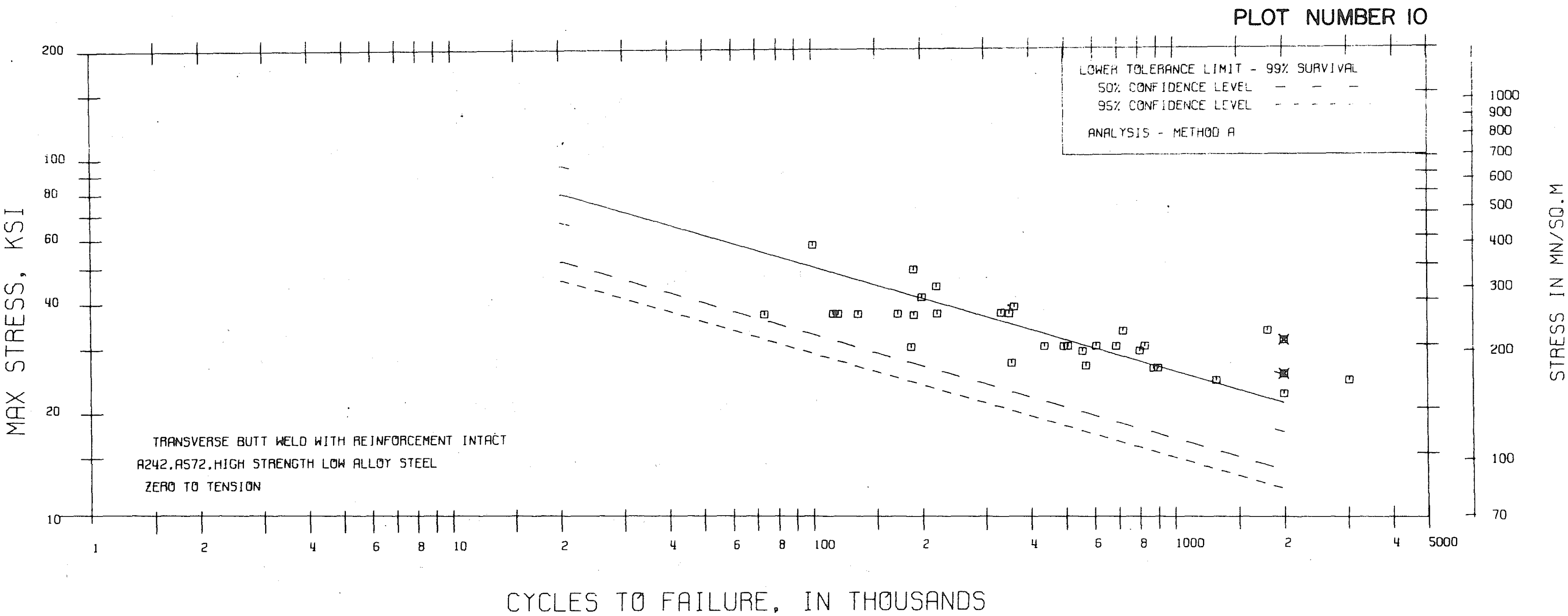
STANDARD ERROR OF ESTIMATE = 1.08035

CORRELATION COEFFICIENT = 0.75739

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.29251

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 95% SURVIVAL 50% CONFIDENCE	LOWER TOLERANCE LIMITS FOR 95% SURVIVAL 95% CONFIDENCE
F(20000) = 79.8 KSI	66.5 KSI	52.0 KSI	46.1 KSI
F(50000) = 61.0	50.9	39.8	35.3
F(100000) = 49.8	41.5	32.5	28.8
F(200000) = 40.7	33.9	26.5	23.5
F(500000) = 31.1	25.9	20.3	18.0
F(1 MILL) = 25.4	21.2	16.6	14.7
F(2 MILL) = 20.7	17.3	13.5	12.0
F(20000) = 550.0 MN/SQ.M	458.5 MN/SQ.M	358.6 MN/SQ.M	318.1 MN/SQ.M
F(50000) = 420.7	350.7	274.3	243.3
F(100000) = 343.5	286.3	224.0	198.7
F(200000) = 280.4	233.8	182.9	162.2
F(500000) = 214.5	178.8	139.9	124.1
F(1 MILL) = 175.1	146.0	114.2	101.3
F(2 MILL) = 143.0	119.2	93.2	82.7



PLOT NUMBER 10
LOWER TOLERANCE LIMIT - 99% SURVIVAL
50% CONFIDENCE LEVEL
95% CONFIDENCE LEVEL
ANALYSIS - METHOD A
TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT
A242,A572,HIGH STRENGTH LOW ALLOY STEEL
ZERO TO TENSION
MAX STRESS, KSI
STRESS IN MN/SQ.M
CYCLES TO FAILURE, IN THOUSANDS

SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT PLOT NUMBER 11

STEEL TYPE =A242,A572,HIGH STRENGTH LOW ALLOY STEEL

STRESS CYCLE = HALF TENSION TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 9

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 20.10590 B =-2.77527

STANDARD ERROR OF ESTIMATE = 0.57093

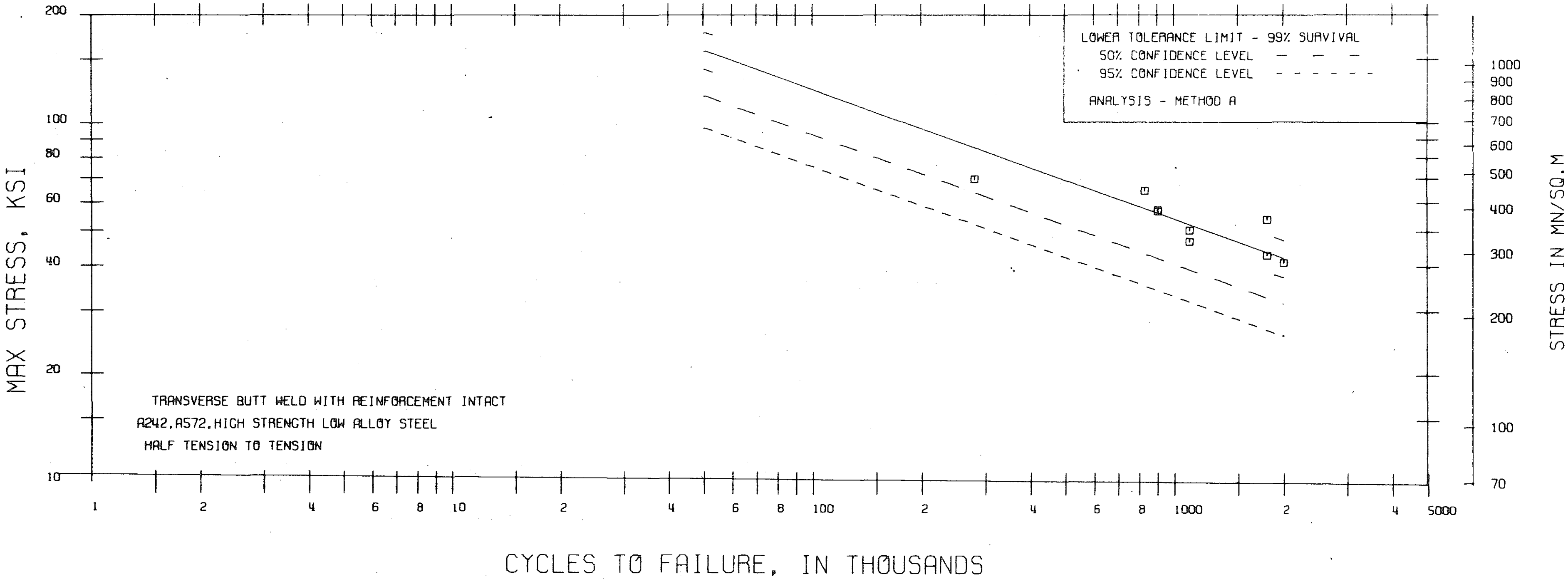
CORRELATION COEFFICIENT = 0.83451

ABSOLUTE VALUE OF SLOPE
OF S-N CURVE = 0.36033

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 95% CONFIDENCE
F(50000) =158.8 KSI	141.1 KSI	119.2 KSI	97.2 KSI
F(100000) =123.7	109.9	92.9	75.7
F(200000) = 96.4	85.6	72.3	59.0
F(500000) = 69.3	61.5	52.0	42.4
F(1 MILL) = 54.0	47.9	40.5	33.0
F(2 MILL) = 42.0	37.3	31.6	25.7
F(50000) =1095.0 MN/SQ.M	972.6 MN/SQ.M	821.9 MN/SQ.M	670.2 MN/SQ.M
F(100000) = 853.0	757.7	640.2	522.1
F(200000) = 664.5	590.2	498.7	406.7
F(500000) = 477.6	424.2	358.5	292.3
F(1 MILL) = 372.1	330.5	279.3	227.7
F(2 MILL) = 289.8	257.4	217.5	177.4

PLOT NUMBER 11



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT

PLOT NUMBER 12

STEEL TYPE =A514,A517,HIGH YIELD STRENGTH Q&T STEEL

STRESS CYCLE = COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 33

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 14.90553 B =-3.22337

STANDARD ERROR OF ESTIMATE = 0.93354

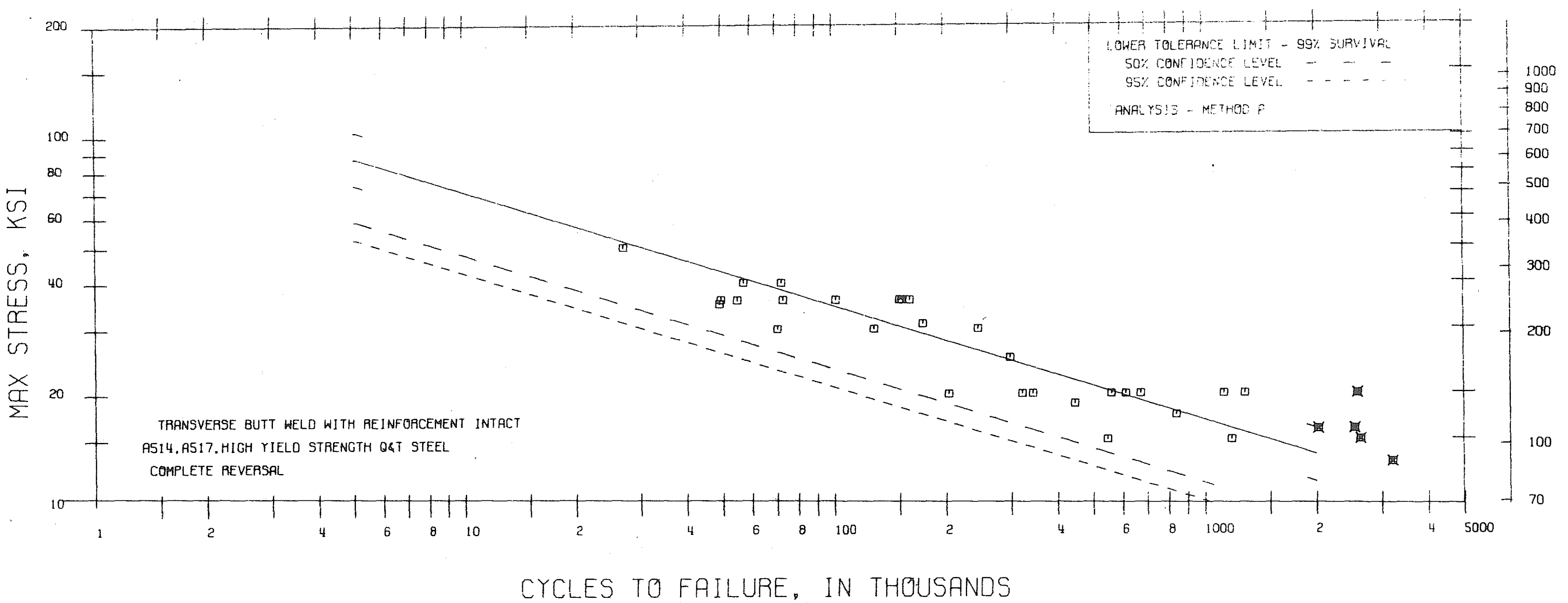
CORRELATION COEFFICIENT = 0.91146

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.31023

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 95% CONFIDENCE
F(5000) = 87.2 KSI	73.8 KSI	58.9 KSI	52.7 KSI
F(10000) = 70.4	59.5	47.5	42.5
F(20000) = 56.7	48.0	38.3	34.3
F(50000) = 42.7	36.1	28.9	25.8
F(100000) = 34.4	29.1	23.3	20.8
F(200000) = 27.8	23.5	18.8	16.8
F(500000) = 20.9	17.7	14.1	12.6
F(1 MILL) = 16.9	14.3	11.4	10.2
F(2 MILL) = 13.6	11.5	9.2	8.2
F(5000) = 601.4 MN/SQ.M	509.0 MN/SQ.M	406.4 MN/SQ.M	363.4 MN/SQ.M
F(10000) = 485.1	410.5	327.8	293.1
F(20000) = 391.2	331.1	264.4	236.4
F(50000) = 294.4	249.2	199.0	177.9
F(100000) = 237.4	201.0	160.5	143.5
F(200000) = 191.5	162.1	129.4	115.7
F(500000) = 144.1	122.0	97.4	87.1
F(1 MILL) = 116.2	98.4	78.5	70.2
F(2 MILL) = 93.7	79.3	63.4	56.6

PLOT NUMBER 12



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT PLOT NUMBER 13

STEEL TYPE =A514,A517,HIGH YIELD STRENGTH Q&T STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 151

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 17.39691 B =-3.19270

STANDARD ERROR OF ESTIMATE = 1.18310

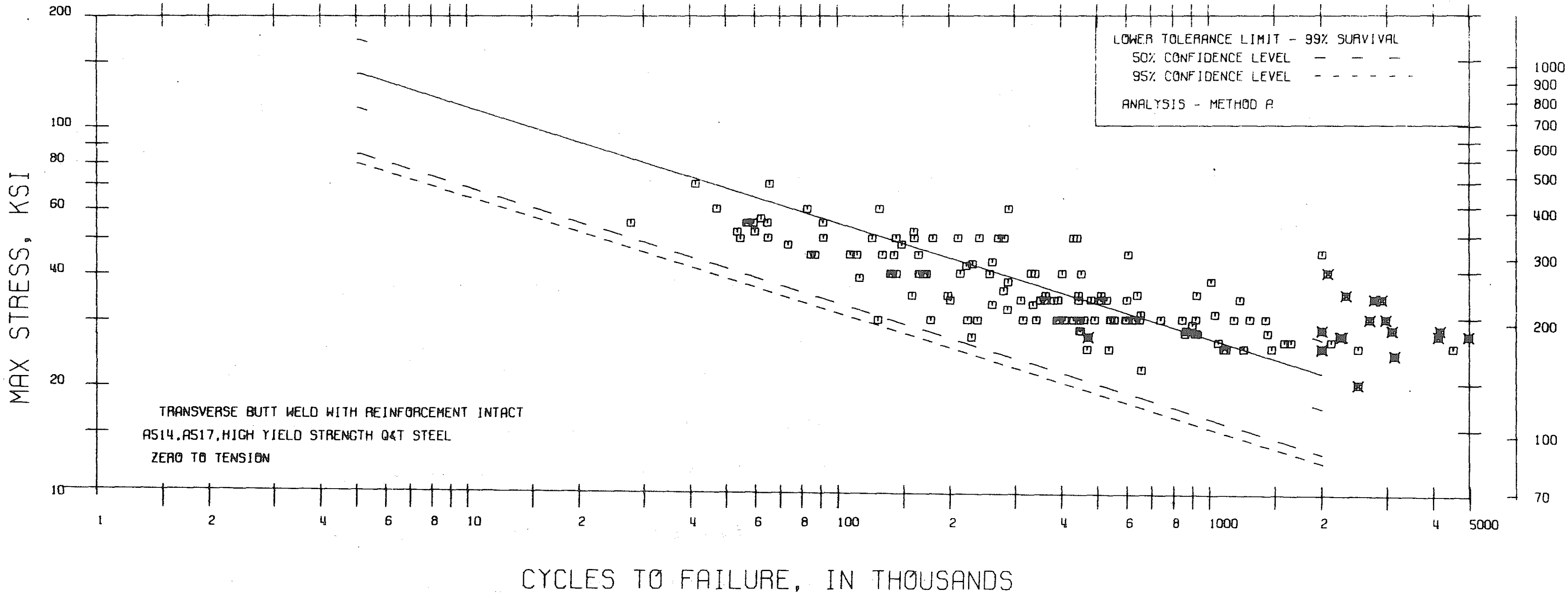
CORRELATION COEFFICIENT = 0.78137

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.31321

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(5000) =139.6 KSI	112.8 KSI	84.9 KSI	80.0 KSI
F(10000) =112.4	90.8	68.3	64.4
F(20000) = 90.4	73.1	55.0	51.8
F(50000) = 67.9	54.8	41.3	38.9
F(100000) = 54.6	44.1	33.2	31.3
F(200000) = 44.0	35.5	26.7	25.2
F(500000) = 33.0	26.7	20.1	18.9
F(1 MILL) = 26.6	21.5	16.1	15.2
F(2 MILL) = 21.4	17.3	13.0	12.2
F(5000) = 962.6 MN/SQ.M	777.6 MN/SQ.M	585.3 MN/SQ.M	551.4 MN/SQ.M
F(10000) = 774.7	625.8	471.0	443.8
F(20000) = 623.5	503.7	379.1	357.2
F(50000) = 468.0	378.0	284.5	268.1
F(100000) = 376.6	304.2	229.0	215.8
F(200000) = 303.1	244.9	184.3	173.7
F(500000) = 227.5	183.8	138.3	130.3
F(1 MILL) = 183.1	147.9	111.3	104.9
F(2 MILL) = 147.4	119.0	89.6	84.4

PLOT NUMBER 13



SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT INTACT

STEEL TYPE =A514,A517,HIGH YIELD STRENGTH Q&T STEEL

STRESS CYCLE = HALF TENSION TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 71

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 20.41510 B =-3.11441

STANDARD ERROR OF ESTIMATE = 0.92399

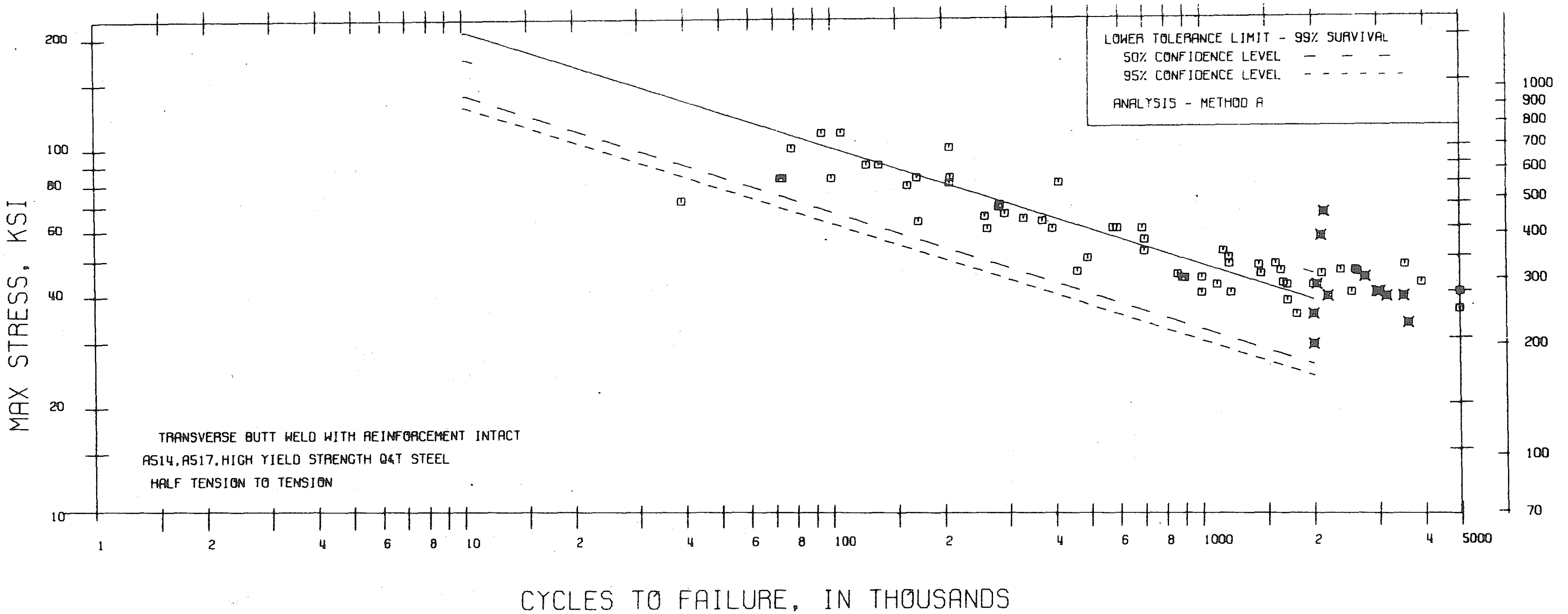
CORRELATION COEFFICIENT = 0.88146

ABSOLUTE VALUE OF SLOPE
OF S-N CURVE = 0.32109

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 50% CONFIDENCE	LOWER TOLERANCE LIMITS FOR 99% SURVIVAL 95% CONFIDENCE
F(10000) =208.7 KSI	175.9 KSI	140.0 KSI	130.2 KSI
F(20000) =167.0	140.8	112.0	104.2
F(50000) =124.5	104.9	83.5	77.6
F(100000) = 99.6	84.0	66.8	62.1
F(200000) = 79.7	67.2	53.5	49.7
F(500000) = 59.4	50.1	39.9	37.1
F(1 MILL) = 47.6	40.1	31.9	29.7
F(2 MILL) = 38.1	32.1	25.5	23.7
F(10000) =1438.7 MN/SQ.M	1212.7 MN/SQ.M	965.0 MN/SQ.M	897.4 MN/SQ.M
F(20000) =1151.7	970.7	772.5	718.3
F(50000) = 858.1	723.3	575.6	535.2
F(100000) = 686.9	579.0	460.7	428.4
F(200000) = 549.8	463.5	368.8	343.0
F(500000) = 409.7	345.3	274.8	255.5
F(1 MILL) = 327.9	276.4	220.0	204.6
F(2 MILL) = 262.5	221.3	176.1	163.7

PLOT NUMBER 14



SPECIMEN TYPE = TRANSVERSE BUTT WELDS WITH REINFORCEMENT REMOVED

PLOT NUMBER 15

STEEL TYPE = A7, A36, MILD STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 15

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 17.82037 B =-3.96627

STANDARD ERROR OF ESTIMATE = 1.56898

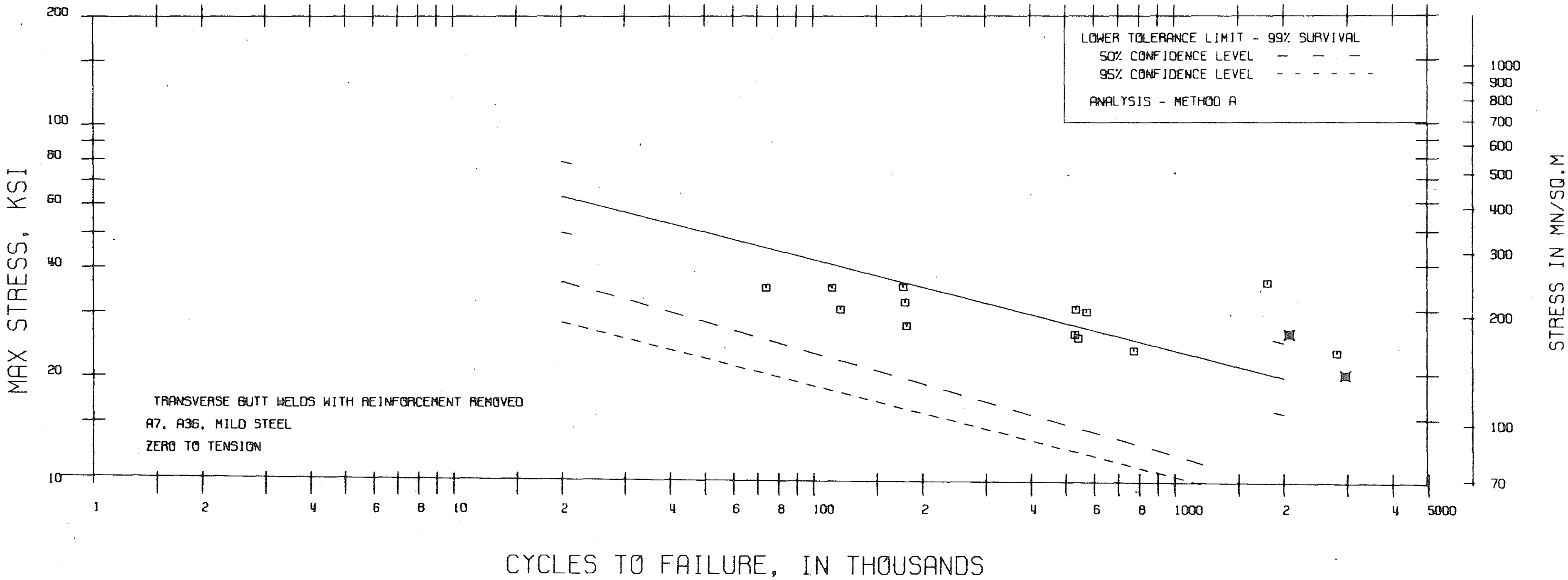
CORRELATION COEFFICIENT = 0.61901

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.25213

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

FATIGUE STRENGTH	-ONE TIMES STANDARD ERROR OF ESTIMATE	LOWER TOLERANCE LIMITS FOR 9[illegible]% SURVIVAL 50% CONFIDENCE	95% CONFIDENCE
F(20000) = 62.6 KSI	49.9 KSI	36.4 KSI	28.1 KSI
F(50000) = 49.7	39.6	28.9	22.3
F(100000) = 41.7	33.2	24.3	18.7
F(200000) = 35.0	27.9	20.4	15.7
F(500000) = 27.8	22.1	16.2	12.5
F(1 MILL) = 23.4	18.6	13.6	10.5
F(2 MILL) = 19.6	15.6	11.4	8.8
F(20000) = 431.7 MN/SQ.M	343.7 MN/SQ.M	251.0 MN/SQ.M	193.6 MN/SQ.M
F(50000) = 342.6	272.8	199.3	153.6
F(100000) = 287.7	229.1	167.3	129.0
F(200000) = 241.6	192.4	140.5	108.3
F(500000) = 191.7	152.7	111.5	86.0
F(1 MILL) = 161.0	128.2	93.6	72.2
F(2 MILL) = 135.2	107.6	78.6	60.6

PLOT NUMBER 15



PLOT NUMBER 16

SPECIMEN TYPE = TRANSVERSE BUTT WELDS WITH REINFORCEMENT REMOVED

STEEL TYPE =A242, HIGH STRENGTH LOW ALLOY STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

NO. OF DATA POINTS USED TO GENERATE S-N CURVE = 10

CONSTANTS COMPUTED FROM REGRESSION ANALYSIS

A = 21.54790 B =-6.16982

STANDARD ERROR OF ESTIMATE = 2.29427

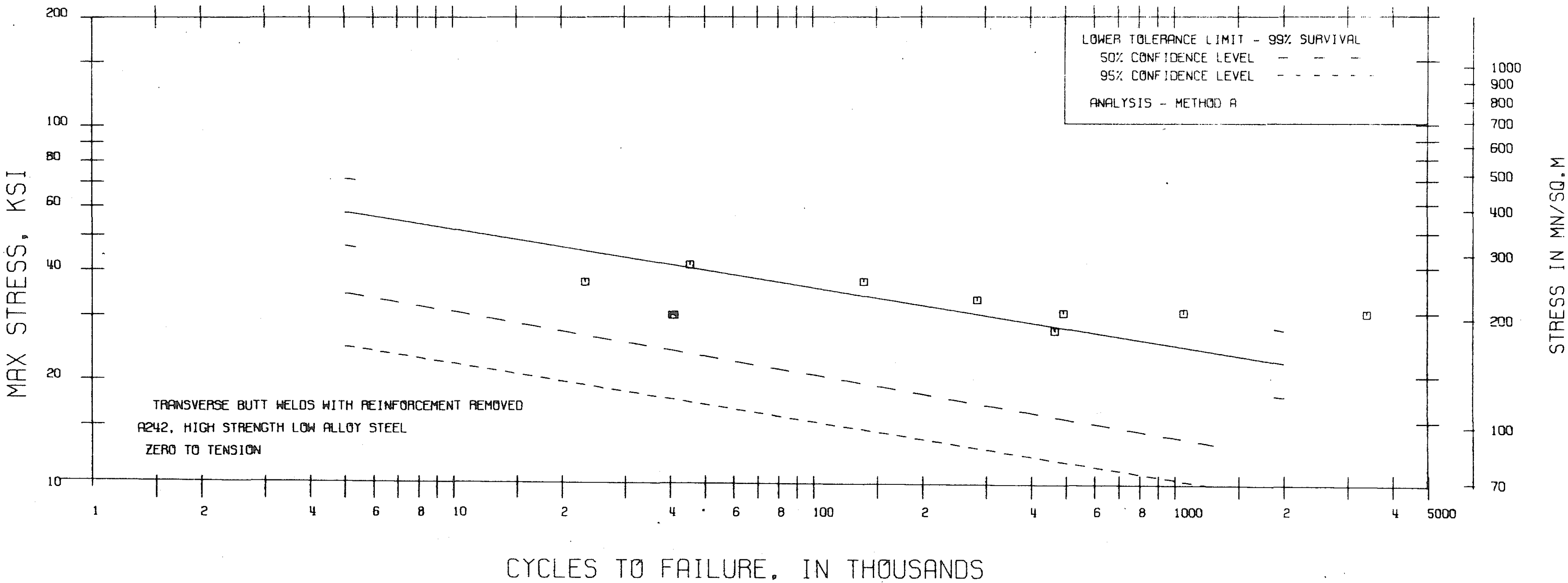
CORRELATION COEFFICIENT = 0.52281

ABSOLUTE VALUE OF SLOPE OF S-N CURVE = 0.16208

COMPUTED VALUES OF FATIGUE STRENGTHS AT SELECTED LIVES

			LOWER TOLERANCE LIMITS FOR 99% SURVIVAL	
FATIGUE STRENGTH		-ONE TIMES STANDARD ERROR OF ESTIMATE	50% CONFIDENCE	95% CONFIDENCE
F(5000)	= 57.7 KSI	46.6 KSI	34.4 KSI	24.6 KSI
F(10000)	= 51.6	41.6	30.8	22.0
F(20000)	= 46.1	37.2	27.5	19.6
F(50000)	= 39.7	32.1	23.7	16.9
F(100000)	= 35.5	28.7	21.2	15.1
F(200000)	= 31.7	25.6	18.9	13.5
F(500000)	= 27.3	22.1	16.3	11.7
F(1 MILL)	= 24.4	19.7	14.6	10.4
F(2 MILL)	= 21.8	17.6	13.0	9.3
F(5000)	= 397.8 MN/SQ.M	321.1 MN/SQ.M	237.4 MN/SQ.M	169.5 MN/SQ.M
F(10000)	= 355.5	286.9	212.1	151.5
F(20000)	= 317.7	256.5	189.6	135.4
F(50000)	= 273.9	221.1	163.4	116.7
F(100000)	= 244.8	197.6	146.1	104.3
F(200000)	= 218.8	176.6	130.5	93.2
F(500000)	= 188.6	152.2	112.5	80.4
F(1 MILL)	= 168.5	136.0	100.6	71.8
F(2 MILL)	= 150.6	121.6	89.9	64.2

PLOT NUMBER 16



PLOT NUMBER 17

SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT REMOVED

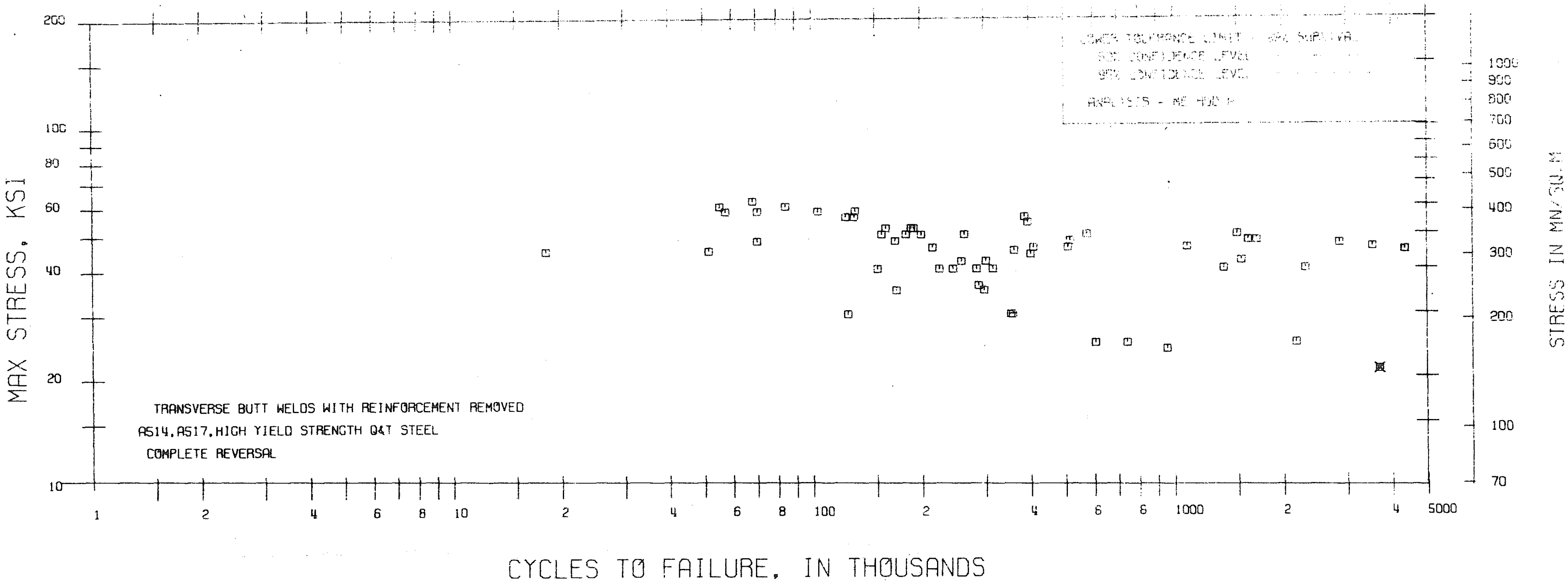
STEEL TYPE = A514,A517,HIGH YIELD STRENGTH Q+T STEEL

STRESS CYCLE = COMPLETE REVERSAL

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

"DATA INADEQUATE FOR GENERATION OF S-N CURVE"

PLOT NUMBER 17



PLOT NUMBER 18

SPECIMEN TYPE = TRANSVERSE BUTT WELD WITH REINFORCEMENT REMOVED

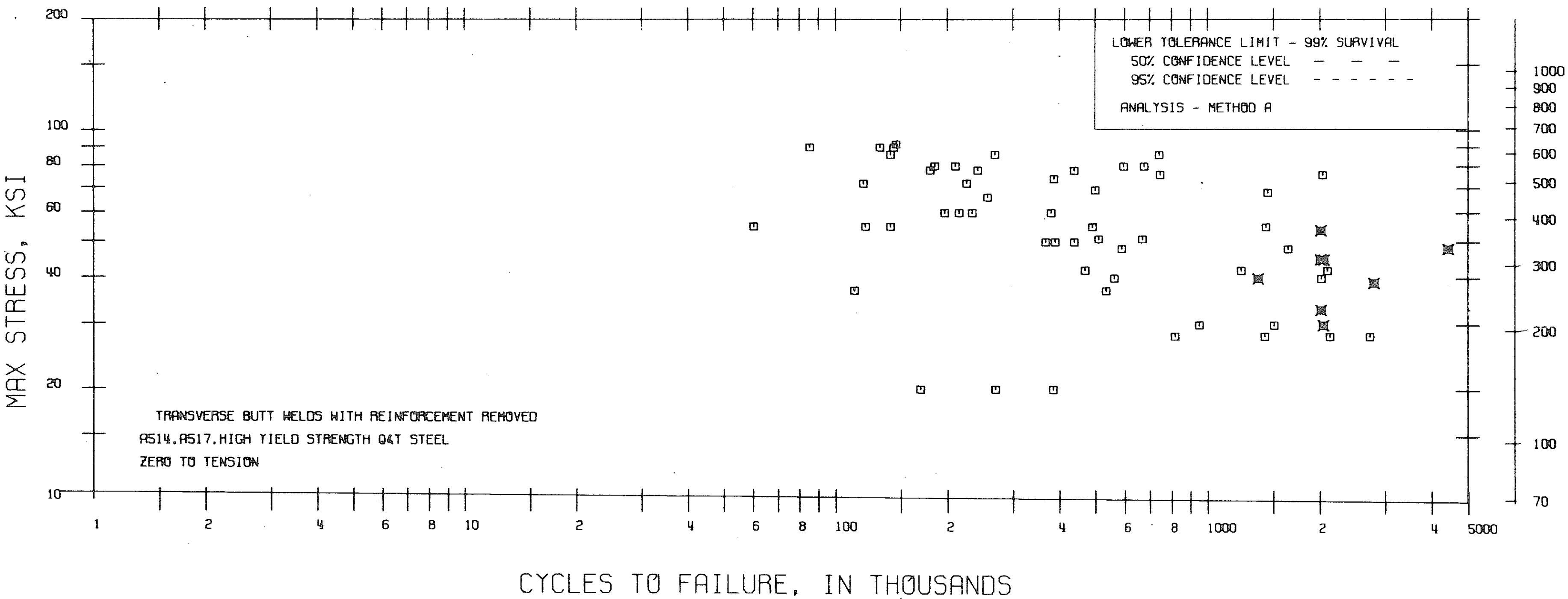
STEEL TYPE = A514,A517,HIGH YIELD STRENGTH Q+T STEEL

STRESS CYCLE = ZERO TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

"DATA INADEQUATE FOR GENERATION OF S-N CURVE"

PLOT NUMBER 18



PLOT NUMBER 19

SPECIMEN TYPE = TRANSVERSE BUTT WELDS WITH REINFORCEMENT REMOVED

STEEL TYPE = A514,A517,HIGH YIELD STRENGTH Q+T STEEL

STRESS CYCLE = HALF TENSION TO TENSION

S-N CURVE = MAXIMUM STRESS VS. CYCLES TO FAILURE

"DATA INADEQUATE FOR GENERATION OF S-N CURVE"

PLOT NUMBER 19