Errata
to
ASME B29.26-2001
Fatigue Testing Power Transmission Roller Chain

On page 4, para. 8.1.4, Eq. (2), the numerator was incorrect. The correct equation is presented below.

$$F_{\max} = \frac{F_t F_u + [F_{\min}(F_u - F_t)]}{F_u} \qquad (2)$$

On page 18, para. D5, fourth paragraph, the first listed nomenclature for mean fatigue strength is incorrect. The correct nomenclature is shown below.

Mean fatigue strength, $X_{M200} = 4395 - 2.701\ (441)$

THE AMERICAN SOCIETY OF MECHANICAL ENGINEERS
Three Park Avenue, New York, NY 10016-5990

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ASME B29.26-2001

(Revision of ASME B29.26M-1996)

FATIGUE TESTING POWER TRANSMISSION ROLLER CHAIN

AN AMERICAN NATIONAL STANDARD

The American Society of Mechanical Engineers

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ASME B29.26-2001
(Revision of ASME B29.26M-1996)

Date of Issuance: March 1, 2002

This Standard will be revised when the Society approves the issuance of a new edition. There will be no addenda issued to this Edition.

ASME will issue written replies to inquiries concerning interpretations of technical aspects of this Standard.

The American Society of Mechanical Engineers
Three Park Avenue, New York, NY 10016-5990

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FOREWORD

The current horsepower ratings for precision power transmission roller chains, to ANSI B29.1, were first published in 1961. The low-speed portion of those ratings was derived from axial fatigue rating data provided by the member companies of the American Chain Association (then the ASCME). Each company determined a chain's fatigue rating a different way, but these differences were not critical because the horsepower ratings were set at a very conservative level.

In 1982, ISO began work on a motorcycle chain standard that included dynamic (fatigue) strength requirements. Furthermore, ISO decided that the development of these dynamic strength requirements for the motorcycle chain standard would set a precedent for including dynamic strength requirements in other chain standards.

During the review of the proposed motorcycle chain standard, this committee found that several different test procedures and analysis methods were in use that could produce significantly different fatigue strength results for the same chain test sample. It seemed obvious that a uniform testing and analysis procedure was needed, so the committee initiated work on this Standard. That edition of ASME B29.26M was approved by the American National Standards Institute on December 9, 1996.

This 2001 revision of B29.26 incorporates several improvements. A conformance test was added to evaluate a chain's conformance to dynamic strength requirements in related B29 product standards. The number of tests in a staircase was revised to require more tests for four or five level staircases. An appendix was added to describe the use of a Probit analysis for setting step size. And, an appendix was added to give a method for adjusting a chain's fatigue strength from a short test specimen (five pitches) to a longer drive chain (one hundred pitches).

This edition of B29.26 was approved by the American National Standards Institute on November 8, 2001.

ASME B29 COMMITTEE
Chains, Attachments, and Sprockets for Power Transmission and Conveying

(The following is the roster of the Committee at the time of approval of this Standard.)

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General. ASME Standards are developed and maintained with the intent to represent the consensus of concerned interests. As such, users of this Standard may interact with the Committee by requesting interpretations, proposing revisions, and attending Committee meetings. Correspondence should be addressed to:

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Proposing Revisions. Revisions are made periodically to the Standard to incorporate changes that appear necessary or desirable, as demonstrated by the experience gained from the application of the Standard. Approved revisions will be published periodically.

The Committee welcomes proposals for revisions to this Standard. Such proposals should be as specific as possible, citing the paragraph number(s), the proposed wording, and a detailed description of the reasons for the proposal, including any pertinent documentation.

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Subject:	Cite the applicable paragraph number(s) and the topic of the inquiry.
Edition:	Cite the applicable edition of the Standard for which the interpretation is being requested.
Question:	Phrase the question as a request for an interpretation of a specific requirement suitable for general understanding and use, not as a request for an approval of a proprietary design or situation. The inquirer may also include any plans or drawings which are necessary to explain the question; however, they should not contain proprietary names or information.

Requests that are not in this format will be rewritten in this format by the Committee prior to being answered, which may inadvertently change the intent of the original request.

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FATIGUE TESTING POWER TRANSMISSION ROLLER CHAIN

1 SCOPE

This Standard covers fatigue testing, in axial tension, of power transmission roller chains in ASME B29.1M and ASME B29.3M, and nonstandard variants of those chains.

2 PURPOSE

The purpose of this Standard is to provide a uniform, reliable method of determining the fatigue strength of power transmission roller chains so that equivalent and comparable results can be obtained from axial fatigue testing at different laboratories.

3 DEFINITIONS AND NOMENCLATURE

amplitude, load (F_a): one-half the difference between the maximum load and the minimum load, measured in pounds force (newtons)

cycles (N): the number of load cycles, at a single load, applied to a specimen chain at a particular time in the test

cycles to failure (N_f): the number of load cycles sustained by the specimen chain at the time of failure

cycles to failure, average (N_a): the calculated mean number of cycles to failure, at a single load, for a test series

cycles to failure, minimum (N_m): the calculated minimum number of cycles to failure, at a single load, for a test series, with 0.977 probability of survival based on a log-normal distribution. Also known as endurance limit.

endurance (N_e): the predetermined number of cycles at which a test will be discontinued without failure of the specimen chain

failure (X): separation, or significant elongation at reduced load, of the specimen chain resulting from fatigue fracture of a link plate (normal) or a pin (uncommon) before endurance. The letter X is used to designate a failure when plotting test data.

fatigue limit (F_d): the test load, corrected to zero minor load, at which there is a calculated 0.135% probability of failure at 10^7 load cycles, measured in pounds force (newtons). This approximates the load below which a chain may endure an infinite number of load cycles.

fatigue strength, average (F_b): the calculated average fatigue strength of a test lot, at 10^7 load cycles, corrected to zero minor load, measured in pounds force (newtons). If endurance is not 10^7, note the number of load cycles at endurance.

fatigue strength, minimum (F_e): the test load, corrected to zero minor load, at which there is a calculated 0.135% probability of failure at an endurance less than 10^7, measured in pounds force (newtons). Note the number of load cycles at endurance.

load, major ($F_{\max}$): the maximum value of load in the load cycle, measured in pounds force (newtons)

load, mean (F_m): one-half the sum of the maximum and minimum loads in the load cycle, measured in pounds force (newtons)

load, minor ($F_{\min}$): the minimum value of load in the load cycle, measured in pounds force (newtons)

load, test (F_r): the major load, corrected to zero minor load, at which a test series was run, measured in pounds force (newtons)

run-out (O): the specimen chain runs to endurance without failure. The letter O is used to designate a run-out when plotting test data.

staircase test: in this Standard, a method of testing for roller chain fatigue strength in which the specimens are tested at predetermined equally spaced load levels. The tests then are arranged such that if the previous test fails before endurance, the next test is at the next lower load level, and if the previous test survives to endurance (runs-out), the next test is at the next higher load level. The resulting data plot resembles a staircase.

step (d): the difference between two adjacent test load levels in a staircase fatigue test, measured in pounds force (newtons)

tensile strength, chain, minimum (F_u): the minimum load at which unused, undamaged chains may be expected to fail when subjected to a single tensile load application, measured in pounds force (newtons)

4 REFERENCES

The following is a list of publications referenced in this Standard. Unless otherwise specified, the standard(s) referenced shall be the most recent issue at the time of order placement.

ASME B29.1, Precision Power Transmission Roller Chains, Attachments, and Sprockets
ASME B29.3, Double-Pitch Power Transmission Roller Chains and Sprockets
ASME B29.24, Roller Load Chains for Overhead Hoists

Publisher: American Society of Mechanical Engineers (ASME International), Three Park Avenue, New York, NY 10016-5990; Order Department: 22 Law Drive, P.O. Box 2300, Fairfield, NJ 07007-2300

ASTM E 4, Practices for Force Verification of Testing Machines
ASTM E 467, Practice for Verification of Constant Amplitude Dynamic Loads on Displacements in an Axial Load Fatigue Testing Machine

Publisher: American Society for Testing and Materials (ASTM), 100 Barr Harbor Drive, West Conshohocken, PA 19428

5 TESTING EQUIPMENT

5.1 Testing Machine Type and Size

5.1.1 Machine Type. The tests may be conducted on any one of the following types of fatigue testing machines: mechanical (eccentric crank, rotating mass, resonant spring, etc.), electromechanical, magnetic, hydraulic, or electrohydraulic.

5.1.2 Machine Size. The size of the testing machine shall be such that the maximum test load on the test chain shall be equal to or greater than 10% of the maximum capacity of the machine.

5.2 Load Application

5.2.1 Load Form. The load shall be in axial tension throughout the test.

The machine shall apply a mean load; then cyclically vary the axial tension load, approximately sinusoidally with time, above and below the mean load between predetermined minor and major loads; and then repeat (see Fig. 1).

5.2.2 Loading Frequency. The loading frequency shall not induce a damaging temperature rise in the test specimen. Loading frequencies of up to 200 Hz usually are satisfactory.

5.3 Load Calibration and Verification

5.3.1 Machine Calibration. The testing machine shall be calibrated periodically to maintain suitable accuracy of load application. The machine should be calibrated to within ± 2% of its maximum capacity. The machine should be calibrated in accordance with ASTM E 4.

5.3.2 Load Verification

(a) The action of the test machine shall be analyzed to ensure that the desired form and magnitude of loading is applied.

(b) A load-monitoring system should be mounted in series with the specimen to ensure that the load cycle is maintained throughout the test.

(c) The varying load, determined by suitable dynamic measuring means, should be maintained at all times to within 2% of the operating range of the machine being used. Loads should be verified in accordance with ASTM E 467.

5.4 Additional Machine Requirements

The testing machine shall have

(a) a counter to record the number of load cycles,

(b) a device to stop the machine when the chain fails, and

(c) a device to prevent the machine from restarting after an emergency stop due to power failure, etc.

5.5 Test Fixtures

5.5.1 Flexibility. Test fixtures shall permit free movement of the test chain in both the normal plane of articulation and in the plane perpendicular to that. Typical test fixture arrangements are shown in Fig. 2.

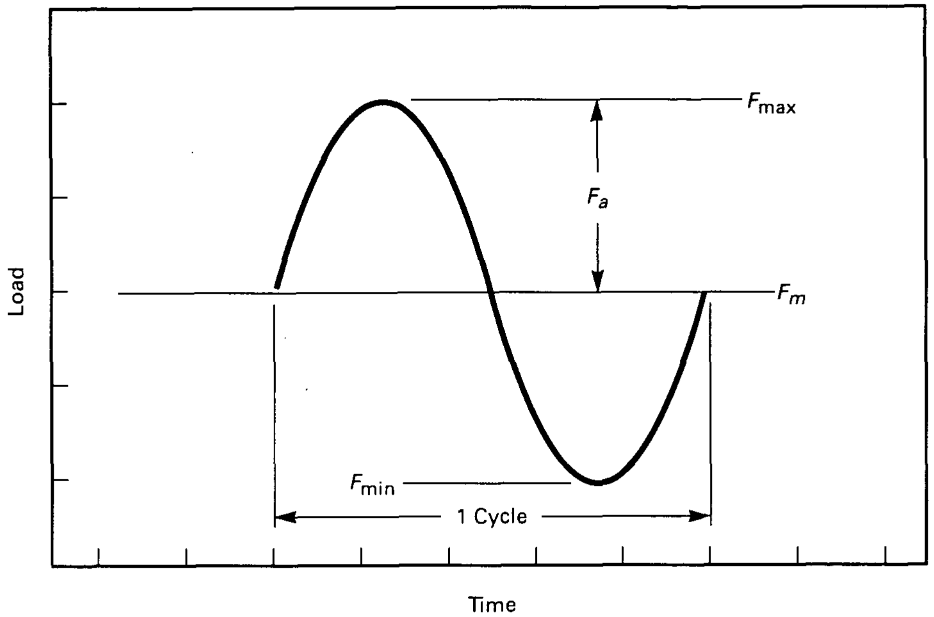


FIG. 1 TYPICAL LOAD CYCLE

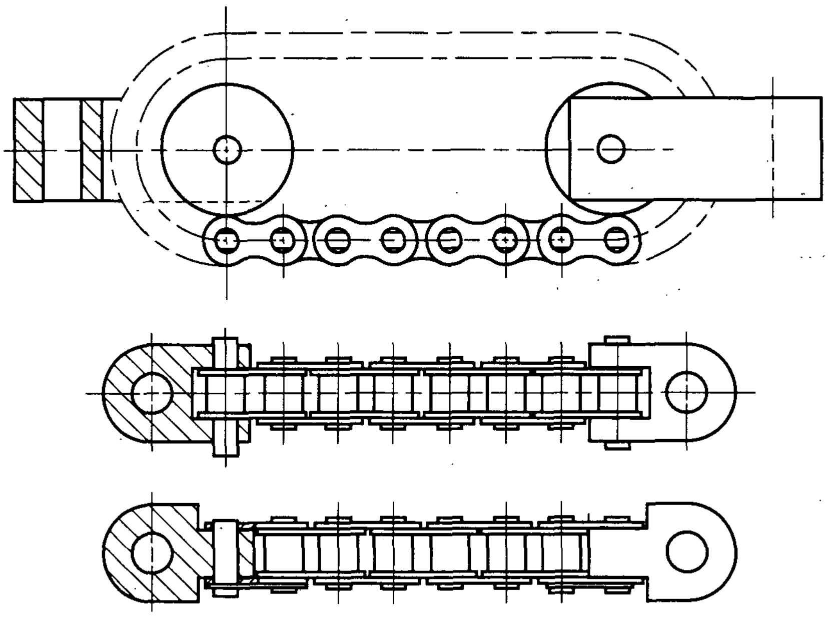


FIG. 2 TYPICAL FATIGUE TEST FIXTURE AND CHAINS

5.5.2 Axial Loading. The load should be applied along the chain's centerline. Avoid misalignment caused by twist or lateral displacement of the fixtures.

5.5.3 Connection. When terminal clevises are used, the size of the hole in the fixture that attaches to the chain should be equal to the size of the bushing hole in the chain. When endless specimens are tested on sprockets or sheaves, the chain shall be restrained from moving about the sheaves to ensure that only the specific sections of the chain are tested.

6 TEST CHAINS

6.1 Condition

Test chains shall be unused, undamaged chains on which all phases of manufacture have been completed. Chain lubrication is discretionary. Test chains should be preloaded to the maximum major load expected to be applied in the test.

6.2 Length

Each test chain shall be at least five free pitches in length. Free pitches are those that do not contact the fixtures. Failures in links that contact the fixtures shall be disregarded. All test chains for a given test series shall be the same length.

7 TEST LOADS

7.1 Minor Load

The minor load shall be at least 1% of the minimum ultimate tensile strength for the subject chain listed in ASME B29.1 or B29.3. The minor load should be set as low, within the recommended operating range, as the testing machine can consistently maintain. A minor load of 1% to 5% of the minimum ultimate tensile strength for the subject chain normally is acceptable.

7.2 Major Load

The major load shall be set at a level that corresponds to the test load (corrected to zero minor load) required by ASME B29.1, or by the type of test described in this Standard.

7.3 Test Load, Corrected to Zero Minor Load

The major load shall be corrected to zero minor load to obtain a representative test load. The test load, corrected to zero minor load, shall be calculated by the Johnson-Goodman straight-line method [see Eq. (1) and Fig. 3].

$$F_t = \frac{F_u(F_{max} - F_{min})}{F_u - F_{min}} \tag{1}$$

8 TESTING PROCEDURES

8.1 Conformance Test

8.1.1 Purpose. A conformance test is to determine if a chain meets the dynamic strength requirements listed for it in ASME B29.1.

8.1.2 Endurance. Endurance shall be 3×10^6 cycles.

8.1.3 Minor Load. The minor load shall be set in accordance with para. 7.1 of this Standard.

8.1.4 Major Load. The major load shall be determined by Eq. (2):

$$F_{max} = \frac{F_t F_u + [F_{min}(F_u F_t)]}{F_u} \tag{2}$$

8.1.5 Test Procedure. Three specimens shall be tested.

An axial tensile load shall be applied, varying approximately sinusoidally between the minor load determined by para. 8.1.3 and the major load determined by para. 8.1.4. The test shall continue to endurance or until the specimen fails, whichever is sooner.

8.1.6 Acceptance. All specimens shall survive to endurance without failure.

8.2 Finite Life Test

8.2.1 Purpose. A finite life test is to determine the relationship between the load and cycles to failure at numbers of cycles less than the inflection point.

8.2.2 Inflection Point. The inflection point is that point at which the cycles to failure begin to increase rapidly with a small decrease in force. It is near 10^6 cycles for roller chain.

8.2.3 Load Levels. There shall be at least two load levels, but not more than four load levels, in a finite life test.

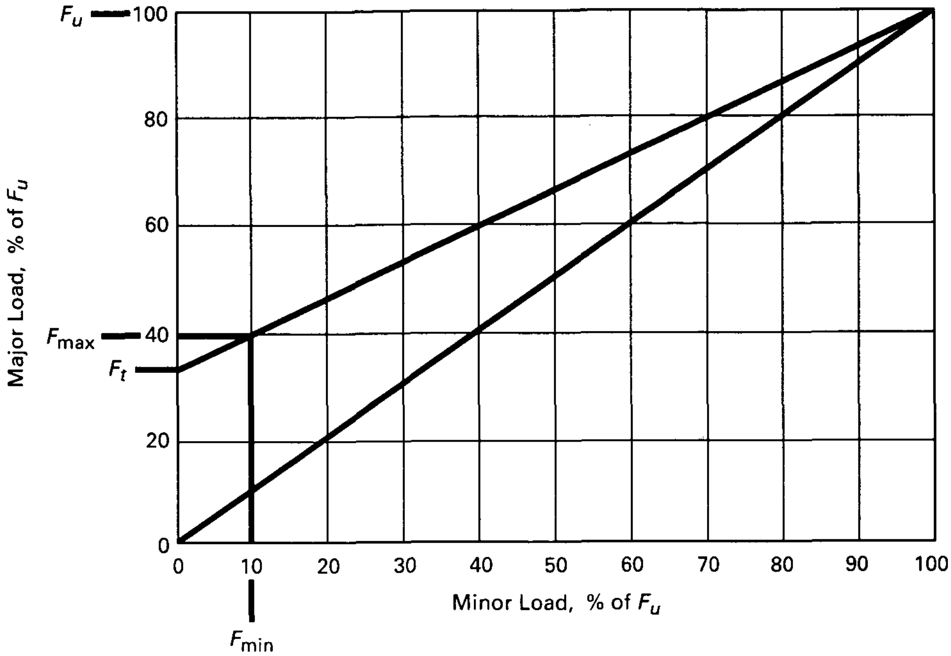


FIG. 3 JOHNSON-GOODMAN DIAGRAM

The maximum test load should not exceed 60% of the minimum tensile strength listed in ASME B29.1.

The minimum test force shall be sufficient to produce all failures before endurance. The minimum test force should be sufficient to produce all failures before 10^6 cycles.

The interval between adjacent force levels should be equal.

8.2.4 Number of Tests. A minimum of fourteen specimens shall be tested. An equal number of tests shall be tested at each force level. Recommended numbers of tests at each force level are: seven specimens at each of two force levels; five specimens at each of three force levels; and four specimens at each of four force levels.

8.3 Staircase Test

8.3.1 Purpose. A staircase test is to determine the fatigue limit, or the high-cycle fatigue strength.

8.3.2 Description. In this Standard, a staircase test is one in which specimens are tested at predetermined, equally spaced, load levels or steps. The tests then are arranged, according to the rules in para. 8.3.7, such that if the previous test fails before endurance, the next test is at the next lower load level, and if the previous test survives to endurance (runs-out), the next test is at the next higher load level. Load levels, or steps, for subsequent tests are determined in a like manner, and the testing continues until the required number of tests are completed.

8.3.3 Endurance. Endurance shall be 10^7 cycles when testing for fatigue limit. Endurance shall be 3 × 10^6 cycles or greater when testing for high-cycle fatigue strength.

8.3.4 Step Size

(a) The step size may be determined from a survival test and abridged Probit analysis. First, a survival test is conducted for the subject chain model. Then, the mean fatigue limit and standard deviation are determined by an abridged Probit analysis. Finally, the step size is set nearly equal to the population standard deviation.

If this method is chosen, the survival test and Probit analysis shall be conducted as described in Appendix A.

(b) If sufficient test data are not available for a survival test, step size, before correcting to zero minor load, may be set empirically by Eq. (3).

$$d = 400P^{1.5}, \text{lb} \tag{3}$$

8.3.5 Selecting the Initial Major Load. The initial test in the staircase should be conducted at the preferred major load two steps higher than the historical

TABLE 1 REQUIRED NUMBER OF DATA POINTS

Confidence on Mean	3-Step Staircase	4-Step Staircase	5-Step Staircase
95%	10	15	20

average fatigue strength. If testing history is not available, the initial test may be run at the preferred major load nearest to 32% of the chain's minimum ultimate tensile strength listed in ASME B29.1.

Preferred major loads are equal to the minor load, plus the step size times an integer [Eq. (4)].

$$F_{max} = F_{min} + (dn_S) \tag{4}$$

where

n_S = integral number of steps

8.3.6 Required Number of Tests. A staircase test shall have the minimum number of tests shown in Table 1.

8.3.7 Rules for Conducting Staircase Tests

(a) A staircase test shall begin with a response reversal — a run-out followed by a failure or a failure followed by a run-out.

(b) A staircase test shall have at least three steps, but should not have more than five steps.

(c) The highest step in a staircase shall contain all failures.

(d) The lowest step in a staircase shall contain all run-outs.

(e) Intermediate steps in a staircase shall contain both failures and run-outs.

9 ANALYZING FATIGUE TESTING DATA

9.1 Analyzing Finite Life Test Data

9.1.1 Data. The data for a finite life analysis shall be gathered in accordance with para. 8.2 of this Standard.

9.1.2 Statistical Distributions. The distribution of fatigue life, at a given force level, is well described by a log normal distribution. The distribution of force, at a given fatigue life (number of cycles), is adequately described by either a normal or log normal distribution. Either a normal or log normal distribution of force may be chosen for analysis.

9.1.3 Determining Force — Life (*F-N*) Lines

9.1.3.1 General Relationships. The relationship between the force, or the logarithm of force, and the logarithm of fatigue life is essentially linear between 10^4 and 10^6 cycles. The relationship of fatigue life at any applied force within the stated limits may be estimated by a regression analysis.

9.1.3.2 Mean Regression Line

(a) If a normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Eqs. (5), (6), and (7).

The relationship between mean fatigue life N and applied force F_a, between 10^4 and 10^6 cycles, is:

$$N = \exp_{10}[\mathrm{Log}N_0 + m_F F_a] \tag{5}$$

The slope of the line is:

$$m_F = \frac{n_f \Sigma F_{ti} \mathrm{Log}N_i - \Sigma F_{ti} \Sigma \mathrm{Log}N_i}{n\Sigma(F_{ti})^2 - (\Sigma F_{ti})^2} \tag{6}$$

And, the X-intercept, or number of cycles, at zero force, is:

$$N_0 = \exp_{10}\left[\frac{\Sigma \mathrm{Log}N_i - m_F \Sigma F_{ti}}{n_f}\right] \tag{7}$$

(b) If a log-normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Eqs. (8), (9), and (10).

The relationship between mean fatigue life N and applied force F_a, between 10^4 and 10^6 cycles, is:

$$N = \exp_{10}[\mathrm{Log}N_0 + m_{LF}\mathrm{Log}_a] \tag{8}$$

The slope of the line is:

$$m_{LF} = \frac{n_f \Sigma(\mathrm{Lof}\,F_{ti}\mathrm{Log}N_i) - \Sigma \mathrm{Log}\,F_{ti} \Sigma \mathrm{Log}N_i}{n\Sigma(\mathrm{Log}\,F_{ti})^2 - (\Sigma \mathrm{Log}\,F_{ti})^2} \tag{9}$$

And, the X-intercept, or number of cycles, at one unit force, is:

$$N_1 = \exp_{10}\left[\frac{\Sigma \mathrm{Log}N_i - m_{LF} \Sigma \mathrm{Log}\,F_{ti}}{n_f}\right] \tag{10}$$

9.1.3.3 Minimum Regression Line

(a) If a normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Eqs. (11) and (12).

The standard deviation of the logarithm of fatigue life from the mean line, between 10^4 and 10^6 cycles, is:

$$S_{\mathrm{Log}N} = \left[\frac{\Sigma\mathrm{Log}N_i^2 - \mathrm{Log}N_0\Sigma\mathrm{Log}N_i - m_F\Sigma(\mathrm{Log}N_iF_{ti})}{n_f - 2}\right]^{0.5} \quad (11)$$

And, the relationship between minimum fatigue life $N_{\min}$ and applied force F_a, between 10^4 and 10^6 cycles, with 0.97725 probability of survival, is:

$$N_{\min} = \exp_{10}[\mathrm{Log}N_0 - 2S_{\mathrm{Log}N} + m_FF_a] \quad (12)$$

(b) If a log normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Eqs. (13) and (14).

The standard deviation of the logarithm of fatigue life from the mean line, between 10^4 and 10^6 cycles, is:

$$S_{\mathrm{Log}N} = \left[\frac{\Sigma\mathrm{Log}N_i^2 - \mathrm{Log}N_0\Sigma\mathrm{Log}N_i - m_{LF}\Sigma(\mathrm{Log}N_i\mathrm{Log}F_{ti})}{n_f - 2}\right]^{0.5} \quad (13)$$

And, the relationship between minimum fatigue life $N_{\min}$ and applied force F_a, between 10^4 and 10^6 cycles, with 0.97725 probability of survival, is:

$$N_{L\min} = \exp_{10}[\mathrm{Log}N_0 - 2S_{\mathrm{Log}N} + m_{LF}\mathrm{Log}F_a] \quad (14)$$

9.2 Analyzing Staircase Test Data

9.2.1 Calculate Test Loads (Correct Major Loads to Zero Minor Load). All test loads in the staircase shall be calculated (major loads shall be corrected to zero minor load) in accordance with para. 7.3 of this Standard before beginning the analysis.

9.2.2 Plot Staircase Test Data

(a) Staircase test data should be plotted as shown in Fig. 4 to ensure that the rules for generating a valid staircase are followed.

(b) Add a "phantom" data point prior to the first test data point in accordance with B1 in Appendix B.

(c) Add a "phantom" data point following the final test data point in accordance with B2 in Appendix B.

9.2.3 Calculate Mean Fatigue Strength. The mean, or average, fatigue strength shall be calculated by Eq. (15).

$$F_b = \frac{\Sigma F_t}{n_s} \quad (15)$$

where

n_s = total number of tests in staircase, including failures, run-outs, and phantom points

9.2.4 Calculate Standard Deviation. The sample standard deviation, S, shall be calculated by Eq. (16).

$$S = \sqrt{\frac{\Sigma F_t^2}{n_s} - \left(\frac{\Sigma F_t}{n_s}\right)^2} \quad (16)$$

9.2.5 Calculate Fatigue Limit, or Minimum Fatigue Strength. The minimum fatigue strength shall be calculated by Eq. (17).

$$F_e = F_b - 3S + d \quad (17)$$

See Appendix C for information on adding d in Eq. (17).

The term fatigue limit, F_d, applies only for endurance at 10^7 cycles.

9.2.6 Extrapolating Minimum Fatigue Strength to 10^7 Cycles

(a) If endurance is set between 3×10^6 and 10^7 cycles, the results may be extrapolated to 10^7 cycles. The results may be extrapolated along the slope of the Load-Cycles line between 3×10^6 cycles and 10^7 cycles. That slope shall be determined by staircase tests at 3×10^6 cycles, 10^7 cycles, and a minimum of one intermediate endurance.

(b) When extrapolated results are presented, the endurance at which the test was run shall be shown with the note that the results were extrapolated to 10^7 cycles.

(c) One comprehensive study shows that the results may be extrapolated from 3×10^6 cycles to 10^7 cycles along a Log Load-Log Cycles slope of –0.036.

10 PRESENTATION OF TEST RESULTS

10.1 Test Chain Information

10.1.1 Identification. The originator shall provide to the user

(a) the name of the manufacturer of the test chain;

(b) the ANSI or ISO number of the test chain, if applicable;

(c) the pitch of the test chain;

Test Force	Invalid Tests		Valid Staircase Tests											
$F_t + 2d$	X													
$F_t + d$		X					X				X		X	
F_t				X		O		X		O		O		#
$F_t - d$			#		O				O					

O = run-out
X = failure
# = phantom point

FIG. 4 STAIRCASE DATA PLOT

(d) a brief description of the test chain, if it is a variant of a standard chain; and

(e) the length, in free pitches, of the test specimens.

10.1.2 Mechanical Properties. The originator should provide to the user

(a) the results of tensile tests on specimens from the same lot as the fatigue test chains;

(b) the results of pin and bushing press-out-force tests on specimens from the same lot as the fatigue test chains;

(c) the results of any other tests on the chain, subassemblies, or individual parts, e.g., part hardness and link plate tensile tests; and

(d) the findings of any visual examinations on the chain or component parts.

10.2 Test Equipment and Procedures

10.2.1 Test Equipment. The originator shall provide to the user

(a) the manufacturer and type of testing machine;

(b) the rated capacity of the test machine;

(c) the number of machines used, if more than one; and

(d) the method of dynamic load verification and monitoring.

10.2.2 Test Procedures. The originator shall provide to the user

(a) the type of test: a staircase test to determine fatigue strength or an endurance test to determine fatigue life;

(b) the purpose of the test, e.g., to determine fatigue strength of production chain, to evaluate proposed alternative designs or processes, or to verify the effect of a design or process change;

(c) the number of cycles to endurance, if it is a staircase test;

(d) the cyclic loading frequency, load cycles per minute; and

(e) any ambient or test conditions that could add non-random variation to the test results.

10.3 Test Results

10.3.1 Final Results of Staircase Tests. The originator shall provide to the user

(a) the number of specimens tested;

(b) the average fatigue strength, corrected to zero minor load, calculated by Eq. (2); and

(c) the minimum fatigue strength, or fatigue limit, corrected to zero minor load, calculated by Eqs. (3) and (4). The term fatigue limit shall only be used when endurance is set at 10^7 cycles.

10.3.2 Final Results of Endurance Tests. The originator shall provide to the user

(a) the number of specimens tested;

(b) the test load at which the series was tested;

(c) the average fatigue life, calculated by Eq. (5); and

(d) the minimum fatigue life, calculated by Eqs. (6) and (7).

10.3.3 Tabular Presentation of Test Results. The originator should provide a table of test results to the user. When a table of results is presented, it shall include

(a) identification of the test specimen;

(b) the test sequence and the order in which the specimens were run;

(c) the major and minor load used in each test;

(d) the number of cycles at which each test was terminated;

(e) the reason each test was terminated, and, if it was a failure, the component of the chain that failed;

(f) a brief summary of the post-test examination, if any was done;

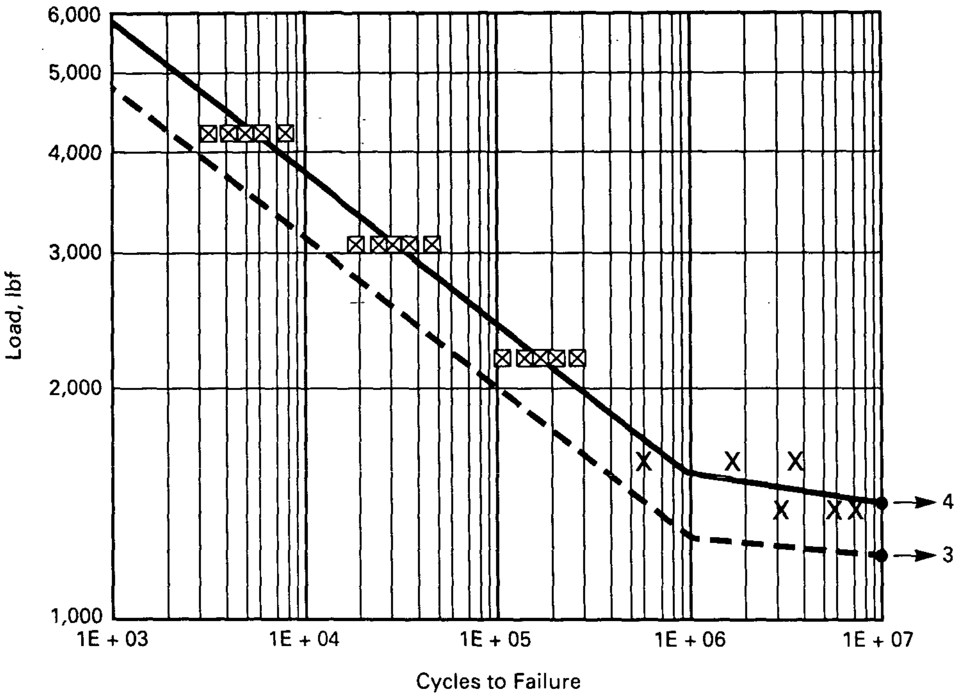
(g) the loading frequency, if it varies from specimen to specimen; and

(h) the machine used for each test, if more than one machine was used.

10.3.4 Graphical Presentation of Test Results. If sufficient test data are generated, and the user so requests, the originator should present the test results in graphical form. The most common graphical method of presenting fatigue test data is the Woehler diagram, or *F-N* plot. The dependent variable, fatigue life in cycles, is plotted on the abscissa, a logarithmic scale. The independent variable, test load in pounds force or newtons, is plotted on the ordinate, an arithmetic or logarithmic scale. For roller chain test data, a logarithmic ordinate scale should be used.

Roller chain fatigue test results are acceptably represented by two straight lines. One is a horizontal line extending from the fatigue strength at 10^7 cycles to 10^6 cycles; or a nearly horizontal line extending from the fatigue strength at 10^7 cycles to 10^6 cycles at a slope determined by the procedure described in para. 7.3.4. The other is a regression line calculated from fatigue life testing data according to para. 9.4.

The failures, [*X*], from fatigue life tests shall be plotted on the test load level at the number of cycles at which failure occurred. Likewise, the failures, *X*, from staircase tests shall be plotted on the test load level at the number of cycles at which failure occurred. The run-outs, *O*, from staircase tests shall be plotted on the test load level at the predetermined number of cycles for endurance, with an arrow extending to the right. When there are multiple run-outs at the same load level, the number of run-outs shall be noted just to the right of the arrow head. All test data points shall be plotted on graphs with the regression lines representing fatigue life and fatigue strength. An example of graphical presentation of fatigue testing data is shown in Fig. 5.



GENERAL NOTES:
(a) ⊠ *failures in finite life test*
(b) X failures in staircase test
(c) ● run-outs in staircase test

FIG. 5 TYPICAL FATIGUE TEST DATA PLOT

NONMANDATORY APPENDIX A
SURVIVAL METHOD WITH ABRIDGED PROBIT ANALYSIS

A1 PURPOSE

A survival test, with a Probit analysis, is the most accurate method of determining the mean fatigue limit and its standard deviation. It may also be used to determine the step size for future staircase testing of a specific model of chain.

A2 DESCRIPTION

The survival test is a procedure in which groups of chain specimens are tested at different load levels such that the central load level contains approximately 50% failures, the highest load level contains 90% to 95% failures, and the lowest load level contains 5% to 10% failures. An abridged Probit analysis is used to estimate the mean fatigue limit and standard deviation of the tested population. The step size is then set nearly equal to the standard deviation for future staircase testing of the subject chain model.

A3 TEST PROCEDURE

A3.1 Test Specimens

Prepare at least fifty, and preferably one hundred, test specimens in accordance with Section 6. All test specimens should be from the same production lot.

Additional test specimens should be provided for preliminary or invalid tests.

A3.2 Endurance

Endurance shall be set at 10^7 cycles.

A3.3 Load Levels

There should be five load levels in the survival test; one giving approximately 50% failures before endurance (very close to the mean), two load levels above that, and two below. There may be only four load levels if the mean falls approximately midway between two force levels.

The interval between adjacent load levels shall be uniform.

TABLE A1 ALLOCATION OF TEST SPECIMENS FOR FIVE LOAD LEVELS

Expected Percent Run-Outs	Relative Group Size
25 to 75	1.0
15 to 20 or 80 to 85	1.5
10 or 90	2.0
5 or 95	3.0
2 or 98	5.0

TABLE A2 ALLOCATION OF TEST SPECIMENS FOR FOUR LOAD LEVELS

Expected Percent Run-Outs	Relative Group Size
20 to 80	1.0
5 to 10 or 90 to 95	2.5

The central load level can be selected by means of a brief (five or six tests) staircase test.

A3.4 Testing

Test specimens shall be allocated to each level according to Table A1 or Table A2 to make the precision at each force level comparable. At least five specimens at each level, and fifty specimens in total, are required for acceptable accuracy.

Each specimen shall be tested until it fails or reaches endurance.

The central force level should have approximately 50% failures.

The highest force level shall have at least one run-out.

The lowest force level shall have at least one failure.

A4 ANALYSIS PROCEDURE

A4.1 General

A Probit analysis is a complex technique for calculating an optimum line through the survival data points using a least-squares analysis to weight each data point according to its distance from the optimum line. This

TABLE A3 SURVIVAL TEST DATA AND PROBIT ANALYSIS

N	*O*	% Survival	*Z*	Load	*X*	*Y*	X^2	Y^2	(*XY*)
	0	99.87%	3.000	2708	...	...	0.0000	...	0
25	24	96.00%	1.751	3125	1.751	3125	3.0649	9,765,625	5,471
10	6	60.00%	0.253	3542	0.253	3542	0.0642	12,545,764	897
10	4	40.00%	−0.253	3958	−0.253	3958	0.0642	15,665,764	−1,003
25	2	8.00%	−1.405	4375	−1.405	4375	1.9742	19,140,625	-6,147
		0.14%	−3.000	4792	...	...	0.0000	...	0
				TOTALS	0.346	15,000	5.168	57,117,778	−782

abridged method calculates a regression line through a single survival point on each force level. The abridged method has proven to be quite adequate for the purposes in this Standard.

A4.2 Distributions

The distributions of survival (cycles to failure) and load should be visually checked by means of a probability plot.

The distribution of cycles to failure at the central and each higher load level should be log-normal.

The distribution of survival across the load levels should be normal.

As the Probit analysis assumes normal distributions, if either distribution is obviously not normal (or log-normal), the analysis should not be attempted.

A4.3 Standard Deviation

The standard deviation of the survival test data, S, which is also the slope of the regression line, shall be estimated by Eq. (A1).

$$S = \frac{n\Sigma XY - \Sigma X \Sigma Y}{n\Sigma X^2 - (\Sigma X)^2} \tag{A1}$$

where

n = number of load levels in the test
X = survival, in Standard Normal Transfer Units, Z
Y = test load, lb

A4.4 Mean Fatigue Limit

The mean fatigue limit of the survival test data, Y_0, which is also the Y-intercept (of force with 50% survival), shall be estimated by Eq. (A2).

$$Y_0 = \frac{\Sigma Y + |S| \Sigma X}{n} \tag{A2}$$

A5 STEP SIZE

The step size for subsequent staircase testing shall be set to between 67% and 150% of the standard deviation. The step size should be set nearly equal to the standard deviation.

A6 EXAMPLE

A survival test was conducted with twenty specimens of #80 chain tested at each of six load levels. All failures were obtained at the highest force level and all run-outs were obtained at the lowest force level. Survival data from the remaining four load levels were:

Load	N	Failures	Run-Outs
4375 lb	25	23	2
3958 lb	10	6	4
3542 lb	10	4	6
3125 lb	25	1	24

A table usually is created for the survival test data and preliminary calculations. Table A3 was created for this example.

From this data, the calculated standard deviation was

$$S = \frac{[4 \cdot (-782)] - (0.346 \cdot 15{,}000)}{(4 \cdot 5.168) - (0.346)^2} = -404 \text{ and } |-404| = 404$$

and the mean fatigue limit was

$$Y_0 = \frac{15{,}000 + (404 \cdot 0.346)}{4} = 3785$$

The results of this analysis are plotted in Fig. A1.

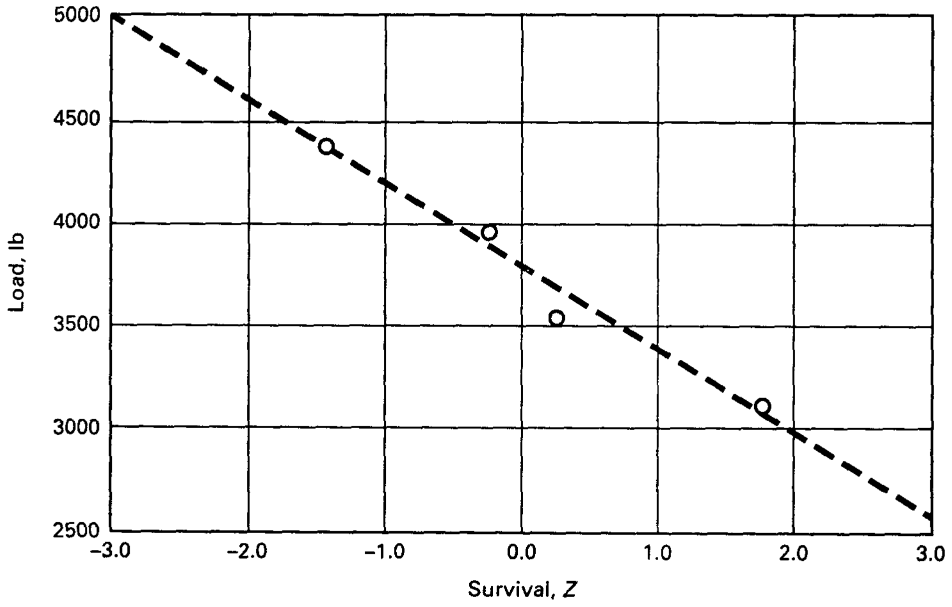


FIG. A1 PROBIT ANALYSIS

NONMANDATORY APPENDIX B
ADDITIONAL "PHANTOM" DATA POINTS

B1 PHANTOM POINT AT THE BEGINNING OF THE STAIRCASE

According to the rules for starting a staircase, the first two tests must be opposite in character: either a run-out and failure or a failure and run-out. Consequently, one data point may be added to the series, prior to the first test data point, even though a test at that point was not actually run. If the first test data point in the series was a run-out, the immediately previous test would have been run at one load level step higher. If the first test data point was a failure, the immediately previous test would have been run one load level step lower. There is no way of knowing if the phantom test was a failure or a run-out, so only one phantom point prior to the first test can be determined.

B2 PHANTOM POINT AFTER THE FINAL TEST IN THE STAIRCASE

According to the rules for selecting the third and subsequent test load levels in a staircase, the next test is to be run at one step higher load if the test just completed was a run-out, and at one step lower load if the test just completed was a failure. Consequently, one data point may be added to the series, after the final test point, even though a test at that point was not actually run. If the final test was a run-out, the next test would be run at one step higher test load. If the final test was a failure, the next test would be run at one step lower test load. There is no way of knowing if the phantom test would be a failure or a run-out, so only one phantom point after the final test point can be determined.

NONMANDATORY APPENDIX C
ADDING ONE STEP TO THE MINIMUM FATIGUE STRENGTH

C1 BASIC CALCULATED MINIMUM

The method for staircase analysis in this Standard utilizes all test points, both failures and run-outs. By definition, all responses at the lowest test force must be run-outs. In practice, the calculated minimum fatigue strength ($F_{mean} - 3S$) always is less than the lowest test force. Consequently, the minimum fatigue strength, with a 0.135% probability of failure, must be greater than the lowest test force.

C2 ADJUSTED MINIMUM

Extensive testing shows that the load at which there is a 0.135% probability of obtaining a failure is approximately one step higher than the load calculated by the conventional statistical method. This is illustrated by Fig. C1. The $-3Z$ probability of failure for the distribution using all of the data is at 3,159 lb. That is less than the lowest load in the staircase (3,542 lb), which must have all run-outs, so it is statistically impossible. The $-3Z$ probability of failure for the distribution using only the failures is at 3,578 lb. The difference of 419 lb is almost exactly equal to the step size of 417 lb.

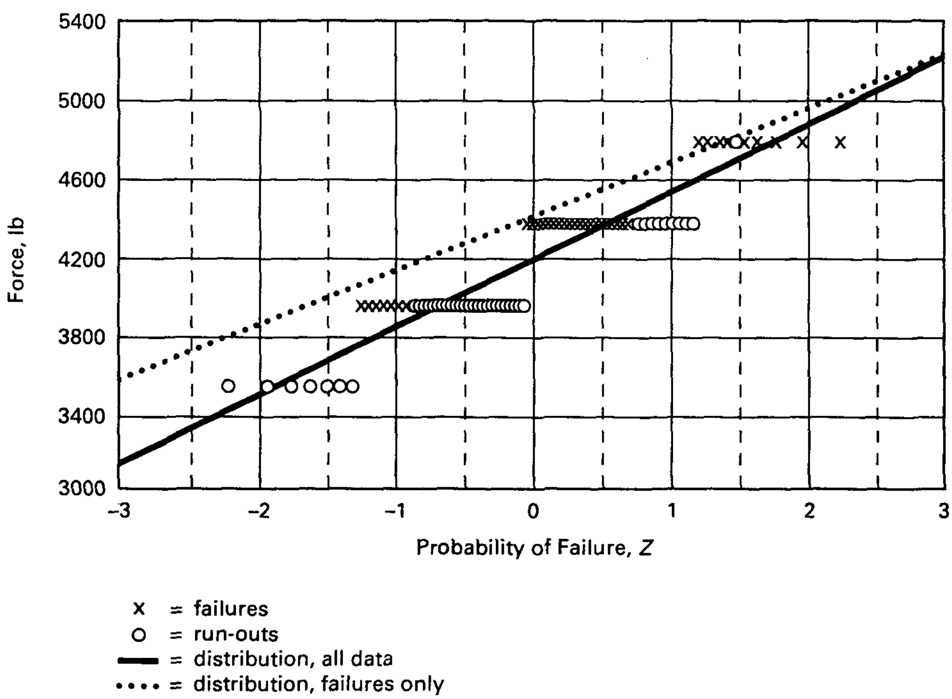


FIG. C1 #80 CHAIN STAIRCASE FATIGUE TEST

NONMANDATORY APPENDIX D
ADJUSTING LABORATORY FATIGUE STRENGTH FOR APPLICATIONS

D1 INTRODUCTION

This Standard prescribes a method for determining the fatigue limit of a sample of roller chains by means of a staircase test under specified laboratory conditions. Some of the conditions are a five-pitch specimen length, all specimens from a single production batch, and a single ten-test to twenty-test staircase. In actual applications, the chain length is usually between fifty and two hundred fifty pitches, the chains used may be from several production batches, and the total production volume greatly exceeds that represented by only ten to twenty tests. Additional analysis methods clearly are needed to evaluate the differences between specified laboratory conditions and actual applications.

D2 SCOPE

This Appendix presents methods for adjusting three of the differences between a chain's fatigue limit under specific laboratory conditions and that same chain's fatigue rating for a variety of applications. Neither this Standard nor this Appendix prescribes a complete method for establishing chain application fatigue ratings.

This Appendix describes methods that may be used to evaluate the effects of three specific differences between the fatigue limit obtained from laboratory testing and a fatigue rating suitable for applications. Experience has shown these methods to be reasonably reliable in evaluating the differences between: a five-pitch to fifteen-pitch specimen length and a much longer drive chain length; the production quantity represented by a ten-test sample and a much larger production quantity; and one production lot and many production lots. Some other factors should be considered, but methods to evaluate them are beyond the scope of this Appendix. There also may be factors that should be considered that are not mentioned in this Appendix.

D3 METHODS

D3.1 Chain Length

A method for evaluating the effect of difference between test specimen length and drive chain length follows.

It can be shown that, for X_{MN} to be the median of the least of N values:

$$A^N = 0.50 \qquad \text{(D1)}$$

Similarly, for X_{-3SN} to be the -3σ of N values:

$$A^N = 0.99865 \qquad \text{(D2)}$$

In this case, N is the number of potential failure sites, or the number of inner plate apertures, in the given chain. Thus, $N = 12$ for a five-pitch test chain with an inner link at each end, and $N = 200$ for a one hundred-pitch drive chain. Calculated values of A^N, for selected values of N, are shown in Table D1 and Fig. D1.

Then:

$$X_{MN} = X_{M1} - Z_{(A,XM)}\, S_P \qquad \text{(D3)}$$

where

X_{MN} = median (mean) fatigue strength of a sample of chains, each with N inner link apertures

X_{M1} = median (mean) fatigue strength of a sample of chains, each with one inner link aperture

$Z_{(A,XM)}$ = standard normal transform corresponding to A^N and X_{MN}

S_P = estimated standard deviation of population when $N = 1$

And:

$$X_{-3SN} = X_{M1} - Z_{(A,-3\sigma)}\, S_P \qquad \text{(D4)}$$

where

X_{-3SN} = minimum ($-3S$) fatigue strength of a sample of chains, each with N inner link apertures

TABLE D1 ADJUSTED PROBABILITIES (A^N) FOR SPECIMEN SIZE (N)

	-3σ		-2σ		-1σ		$-X_M$		$+1\sigma$		$+2\sigma$		$+3\sigma$	
N	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z
1	0.998650	-3.000	0.977250	-2.000	0.841345	-1.000	0.500000	0.000	0.158655	1.000	0.022750	2.000	0.001350	3.000
2	0.999325	-3.205	0.988560	-2.275	0.917248	-1.387	0.707107	-0.545	0.398316	0.258	0.150831	1.033	0.036742	1.790
4	0.999662	-3.399	0.994263	-2.528	0.957731	-1.725	0.840896	-0.998	0.631122	-0.335	0.388370	0.284	0.191682	0.872
8	0.999831	-3.584	0.997128	-2.762	0.978637	-2.026	0.917004	-1.385	0.794432	-0.822	0.623193	-0.314	0.437815	0.157
12	0.999887	-3.689	0.998084	-2.892	0.985707	-2.189	0.943874	-1.588	0.857771	-1.070	0.729595	-0.612	0.576581	-0.193
16	0.999916	-3.761	0.998563	-2.981	0.989261	-2.299	0.957603	-1.724	0.891309	-1.234	0.789426	-0.804	0.661676	-0.417
20	0.999932	-3.816	0.998850	-3.048	0.991400	-2.382	0.965936	-1.824	0.912059	-1.354	0.827655	-0.945	0.718648	-0.579
24	0.999944	-3.863	0.999042	-3.103	0.992828	-2.449	0.971532	-1.904	0.926159	-1.448	0.854163	-1.054	0.759329	-0.704
28	0.999952	-3.900	0.999178	-3.148	0.993849	-2.503	0.975549	-1.969	0.936364	-1.525	0.873616	-1.144	0.789790	-0.806
32	0.999958	-3.930	0.999281	-3.187	0.994616	-2.550	0.978572	-2.025	0.944092	-1.590	0.888496	-1.219	0.813435	-0.891
36	0.999962	-3.958	0.999361	-3.221	0.995213	-2.591	0.980930	-2.073	0.950146	-1.646	0.900245	-1.283	0.832313	-0.963
40	0.999966	-3.986	0.999425	-3.251	0.995690	-2.627	0.982821	-2.116	0.955018	-1.696	0.909755	-1.339	0.847731	-1.027
60	0.999977	-4.079	0.999617	-3.364	0.997125	-2.762	0.988514	-2.274	0.969782	-1.878	0.938894	-1.546	0.895720	-1.258
80	0.999983	-4.144	0.999712	-3.443	0.997843	-2.854	0.991373	-2.381	0.977250	-2.000	0.953811	-1.683	0.920723	-1.410
100	0.999986	-4.200	0.999770	-3.503	0.998274	-2.924	0.993092	-2.462	0.981758	-2.091	0.962875	-1.785	0.936059	-1.523
120	0.999989	-4.238	0.999808	-3.551	0.998561	-2.981	0.994240	-2.527	0.984775	-2.164	0.968965	-1.866	0.946425	-1.611
140	0.999990	-4.275	0.999836	-3.591	0.998767	-3.027	0.995061	-2.580	0.986936	-2.224	0.973339	-1.932	0.953899	-1.684
160	0.999992	-4.303	0.999856	-3.626	0.998921	-3.068	0.995677	-2.626	0.988560	-2.275	0.976632	-1.989	0.959543	-1.745
200	0.999993	-4.359	0.999885	-3.683	0.999137	-3.134	0.996540	-2.701	0.990837	-2.359	0.981262	-2.081	0.967501	-1.845
240	0.999994	-4.396	0.999904	-3.730	0.999280	-3.187	0.997116	-2.761	0.992358	-2.426	0.984360	-2.154	0.972844	-1.924
300	0.999995	-4.433	0.999923	-3.786	0.999424	-3.251	0.997692	-2.833	0.993882	-2.505	0.987469	-2.240	0.978215	-2.018
360	0.999996	-4.470	0.999936	-3.830	0.999520	-3.302	0.998076	-2.890	0.994899	-2.569	0.989546	-2.310	0.981813	-2.093
400	0.999997	-4.508	0.999942	-3.856	0.999568	-3.332	0.998269	-2.923	0.995408	-2.605	0.990587	-2.349	0.983617	-2.135
500	0.999997	-4.545	0.999954	-3.912	0.999655	-3.393	0.998615	-2.992	0.996325	-2.681	0.992462	-2.431	0.986872	-2.222
600	0.999998	-4.582	0.999962	-3.953	0.999712	-3.443	0.998845	-3.047	0.996936	-2.741	0.993715	-2.496	0.989048	-2.292

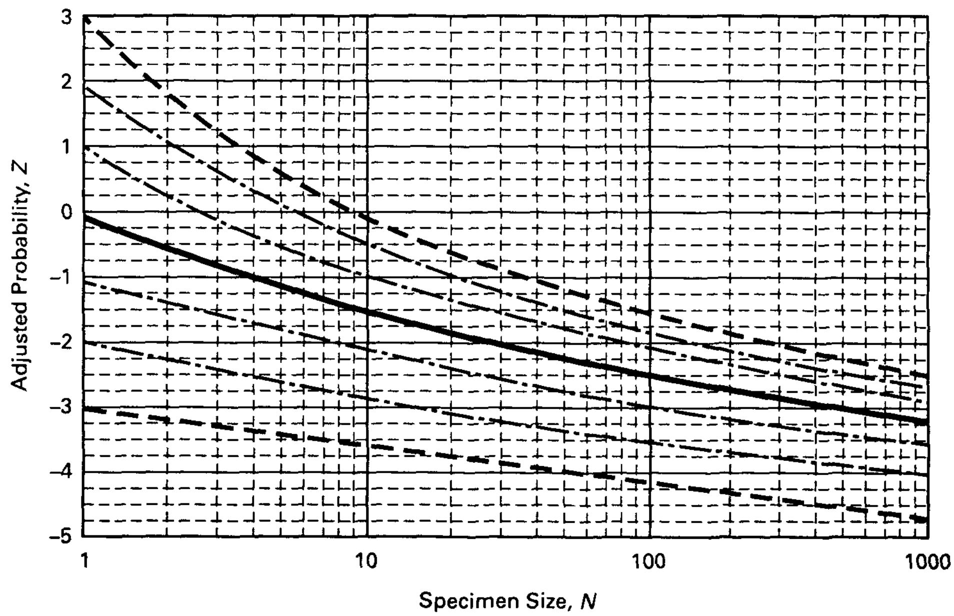


FIG. D1 ADJUSTED PROBABILITIES (A^N) FOR SPECIMEN SIZE (N)

X_{M1} = median (mean) fatigue strength of a sample of chains, each with one inner link aperture

$Z_{(A,-3\sigma)}$ = standard normal transform corresponding to A^N and X_{-3SN}

The standard deviation of the population, S_P, is estimated by simultaneously solving the equations (D3) and (D4). This calculation is an approximation of S_P because the interval between standard deviations is not uniform.

Finally, the mean and minimum fatigue limit of a chain of any length may be estimated by substituting the appropriate values for X_{M1}, SP, $Z_{(A,XM)}$, and $Z_{(A,-3\sigma)}$.

D3.2 Sample Size

When establishing chain application fatigue ratings, the sample selected for staircase testing should be sufficient to minimize statistical error.

A staircase test for establishing chain application fatigue ratings should contain at least thirty specimens, a combination of at least three ten-test staircases.

D3.3 Sample Representativeness

When establishing chain application fatigue ratings, the sample selected for staircase testing should be representative of more than one production batch.

A staircase test for establishing chain application fatigue ratings should contain at least thirty specimens, equally representing at least three different production batches.

D4 OTHER FACTORS

D4.1 Statistical Limits

The definition of fatigue limit states that there is a 0.135% probability of failure at 10^7 cycles. The probability of failure, while operating a chain at its fatigue limit, is small but it does exist. Users should be warned of this possibility of fatigue failure or the chain producer should adjust the ratings for it.

D4.2 Fatigue Life

Limited testing shows there are some link plate fatigue failures beyond 10^7 cycles. That indicates the slope of the F-N line beyond 10^7 cycles may not be quite zero (or ∞). A chain still may fail no matter how carefully selected and maintained. No explicit advice can be given on this, but both users and producers should be aware of this possibility of fatigue failure.

D4.3 Wear

Chain and sprocket wear can reduce the fatigue strength and life of roller chain. Large variation precludes the prediction of wear effects, but here again, both users and producers should be aware of the possibility of fatigue failure.

D4.4 Unidentified Factors

Other factors, not listed here, can affect the fatigue life of roller chain. One way to handle them is by listing the drive conditions under which the ratings apply and exclude everything else.

D5 SAMPLE CALCULATIONS

In the constructed thirty-test staircase example shown in Table D2, each of the three production batches had low variation (3-step staircases), but the means differed by about two steps.

Basic statistics for this staircase are:

Mean fatigue strength, $X_M = 3527$
Standard deviation, $S = 423$
Minimum fatigue strength, $X_{-3S} = 2259$
Minimum fatigue limit, $X_{-3S} + d = 2675$

In the example in Table D2, test chain length was 13 pitches, with inner link each end (N = 28.) Adjustments for chain length are:

$$\begin{aligned} 3527 &= X_{M1} - 1.969S_P \qquad & X_{M1} &= 3527 + 1.969\,(441) \\ \underline{2675} &\underline{= X_{M1} - 3.900S_P} & X_{M1} &= 4395 \\ 852 &= 1.931S_P \\ 441 &= S_P \end{aligned}$$

So, for a drive chain 100 pitches long:

$$\begin{aligned} \text{Mean fatigue strength, } X_{M200} &= 4395 - 2.701\,(4401) \\ &= 4395 - 1191 \\ &= 3204 \\ \text{Minimum fatigue limit, } X_{-3S200} &= 4395 - 4.359\,(441) \\ &= 4395 - 1922 \\ &= 2472 \end{aligned}$$

And, for a drive chain 120 pitches long:

TABLE D2

Test Force	Staircase																													
4375					X		X																							
3958		X		O		O		X		X		X						X												
3542	O		O						O		O		X		X		O		X		X		X				X			
3125														O		O				O		O		X		O		X		O
2708																									O				O	

$$
\begin{aligned}
\text{Mean fatigue strength, } X_{M240} &= 4395 - 2.761\ (4401) \\
&= 4395 - 1218 \\
&= 3177 \\
\text{Minimum fatigue limit, } X_{-3S240} &= 4395 - 4.396\ (441) \\
&= 4395 - 1939 \\
&= 2456
\end{aligned}
$$

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