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Fatigue test method for transmission precision roller chains and leaf chains

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National foreword

This British Standard is the UK implementation of ISO 15654:2015.

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A list of organizations represented on this committee can be obtained on request to its secretary.

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Second edition
2015-09-15

Fatigue test method for transmission precision roller chains and leaf chains

Méthode d'essai de fatigue pour chaînes de transmission de précision à rouleaux et chaînes de levage à mailles jointives

Reference number
ISO 15654:2015(E)

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Foreword

ISO (the International Organization for Standardization) is a worldwide federation of national standards bodies (ISO member bodies). The work of preparing International Standards is normally carried out through ISO technical committees. Each member body interested in a subject for which a technical committee has been established has the right to be represented on that committee. International organizations, governmental and non-governmental, in liaison with ISO, also take part in the work. ISO collaborates closely with the International Electrotechnical Commission (IEC) on all matters of electrotechnical standardization.

The procedures used to develop this document and those intended for its further maintenance are described in the ISO/IEC Directives, Part 1. In particular the different approval criteria needed for the different types of ISO documents should be noted. This document was drafted in accordance with the editorial rules of the ISO/IEC Directives, Part 2 (see www.iso.org/directives).

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For an explanation on the meaning of ISO specific terms and expressions related to conformity assessment, as well as information about ISO's adherence to the WTO principles in the Technical Barriers to Trade (TBT), see the following URL: Foreword — Supplementary information.

The committee responsible for this document is ISO/TC 100, *Chains and chain sprockets for power transmission and conveyors*.

This second edition cancels and replaces the first edition (ISO 15654:2004), which has been technically revised.

Fatigue test method for transmission precision roller chains and leaf chains

1 Scope

This International Standard specifies an axial force fatigue test method for transmission roller chains and leaf chains. The tests being of the fluctuating tension type, carried out at room temperature in air, with the force applied along the longitudinal axis of the chain. It also specifies procedures for statistically analysing the test results and gives formats and elements for presenting the results of fatigue tests and analyses.

2 Normative references

The following documents, in whole or in part, are normatively referenced in this document and are indispensable for its application. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

ISO 606, *Short-pitch transmission precision roller and bush chains, attachments and associated chain sprockets*

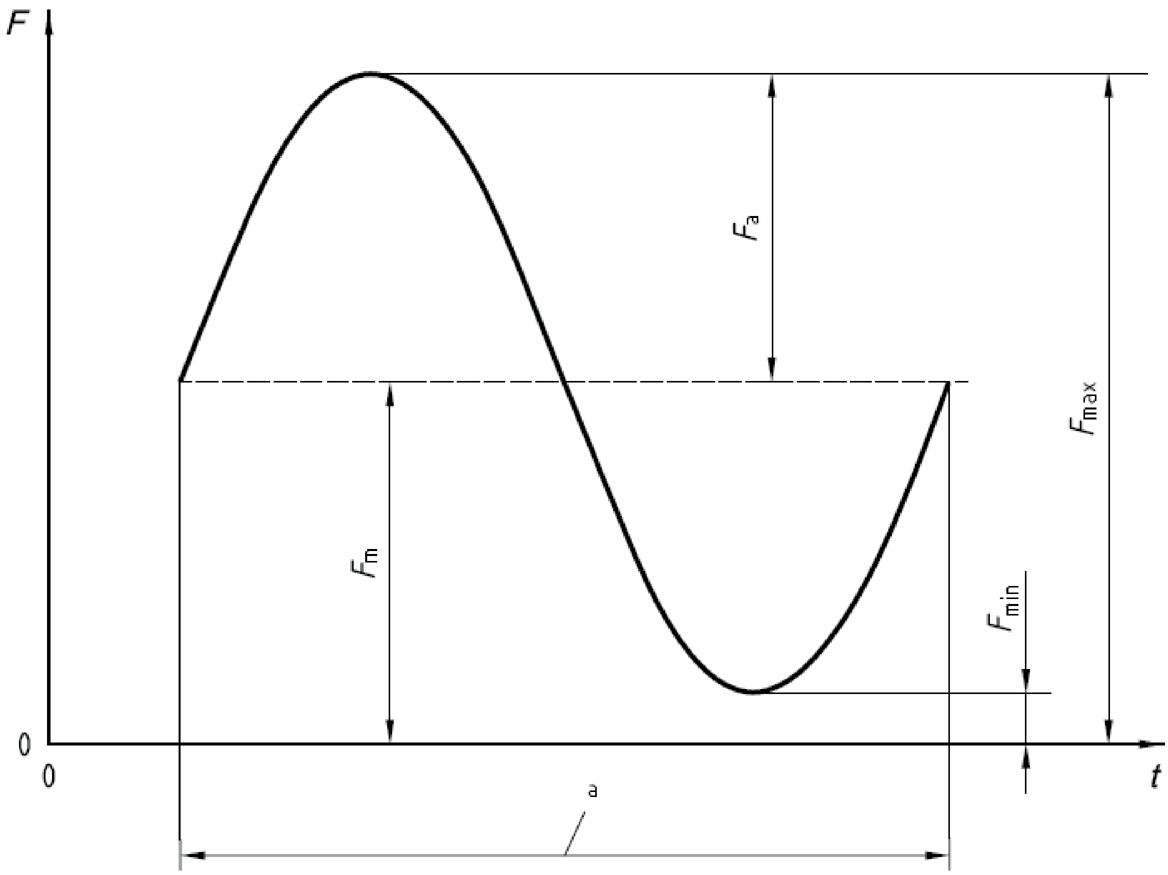
ISO 4347:2015, *Leaf chains, clevises and sheaves — Dimensions, measuring forces, tensile strengths and dynamic strengths*

ISO 10190, *Motorcycle chains — Characteristics and test methods*

3 Symbols

Symbol	Description	Unit
d	Step size — the interval between adjacent force levels in a staircase test [see Formula (5)]	N
F_{max}	Maximum force — maximum value of force in the cycle	N
F_{min}	Minimum force — minimum value of force in the cycle	N
F_m	Mean force — half the sum of the maximum and minimum forces in the force cycle [see Formula (1)]	N
F_a	Force amplitude — half the difference between the maximum force and minimum force [see Formula (2)]	N
F_b	Mean Fatigue Strength — the test force, corrected to zero minimum force, at which there is a 50 % probability of failure at endurance [see Formula (8)]	N
F_{dx}	Fatigue limit — the test force, corrected to zero minimum force, at which there is a calculated 0,135 % probability of failure at 10^7 force cycles. This approximates the force below which a chain can endure an infinite number of force cycles [see Formula (10)]	N
F_d	Test force — the maximum force, corrected to zero minimum force, at which a test was run [see Formula (3)]	N
F_u	Minimum UTS — the minimum tensile strength of chain as specified in ISO 606, ISO 10190 or ISO 4347	N
N	Cycles — the number of cycles, at a given alternating force, applied to a specimen chain at a particular time in the test	—

Symbol	Description	Unit
N_e	Endurance — the predetermined number of cycles at which a test will be discontinued without failure of the specimen chain	—
n	Number of test data points included in the analysis	—
p	Chain pitch	mm
S	Standard deviation — the standard deviation of the staircase test data [see Formula (9)]	N



Key

F force

t time

a One cycle.

$$F_m = \frac{F_{\max} + F_{\min}}{2} \tag{1}$$

$$F_a = \frac{F_{\max} - F_{\min}}{2} \tag{2}$$

Figure 1 — Typical force cycle

4 Principle

Tests are made on transmission chains and leaf chains to determine fatigue properties of chain plates such as those shown on an *F*–*N* diagram or to verify conformance to dynamic strength requirements in ISO 606, ISO 10190 and ISO 4347.

5 Apparatus

5.1 Testing machine

The size of the testing machine shall be selected so that the maximum force on the test specimen is ≥10 % of the maximum capacity of the machine. Tests shall be conducted on a machine capable of applying a sinusoidal fluctuating force to the test specimen in axial tension.

The test frequency shall be chosen so as not to induce a damaging temperature increase in the test specimen.

The machine shall be calibrated periodically in order to maintain suitable accuracy and should be calibrated to within ±2 % of its maximum capacity. A force-monitoring system could be mounted in series with the test specimen to ensure that the force cycle is maintained throughout the test.

The testing machine shall also have

a) a counter to record the number of force 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.

5.2 Test fixtures

The test fixtures shall be capable of transmitting an axial force to the test piece without inducing a subsidiary force caused by the fixtures. Universal type fixtures shall be used for fatigue testing of transmission chains and leaf chains.

The universal fixtures shall be designed according to the chain dimensions specified in the separate standards. Examples of the structure of the fixtures are shown in Figure 2.

Universal fixtures shall permit free movement on both sides of the chain centreline in both the normal plane of articulation and in the transverse plane. For transmission chain the hole in the fixture shall be a size equal to the bush hole diameter of the chain under test. For leaf chain the hole in the fixture shall be a size equal to the clevis hole diameter d_1 shown in ISO 4347:2015, Tables 3 and 4.

NOTE The test specimens all illustrate five free pitches.

When testing chain on sheaves, the chain shall be restrained from moving around the sheaves to ensure that only specific pitches of the chain are tested.

6 Test specimens

6.1 At least five free pitches of chain shall be used as a fatigue test specimen, except for chain pitch over 50,8 mm where a minimum of three free pitches are acceptable.

NOTE Failures in links that contact the fixtures do not constitute part of the test.

Free pitches are those chain pitches that do not contact the fixtures.

6.2 The test specimens shall be unused, undamaged chains on which all phases of manufacture have been completed. The final lubricant type is discretionary.

7 Test procedure

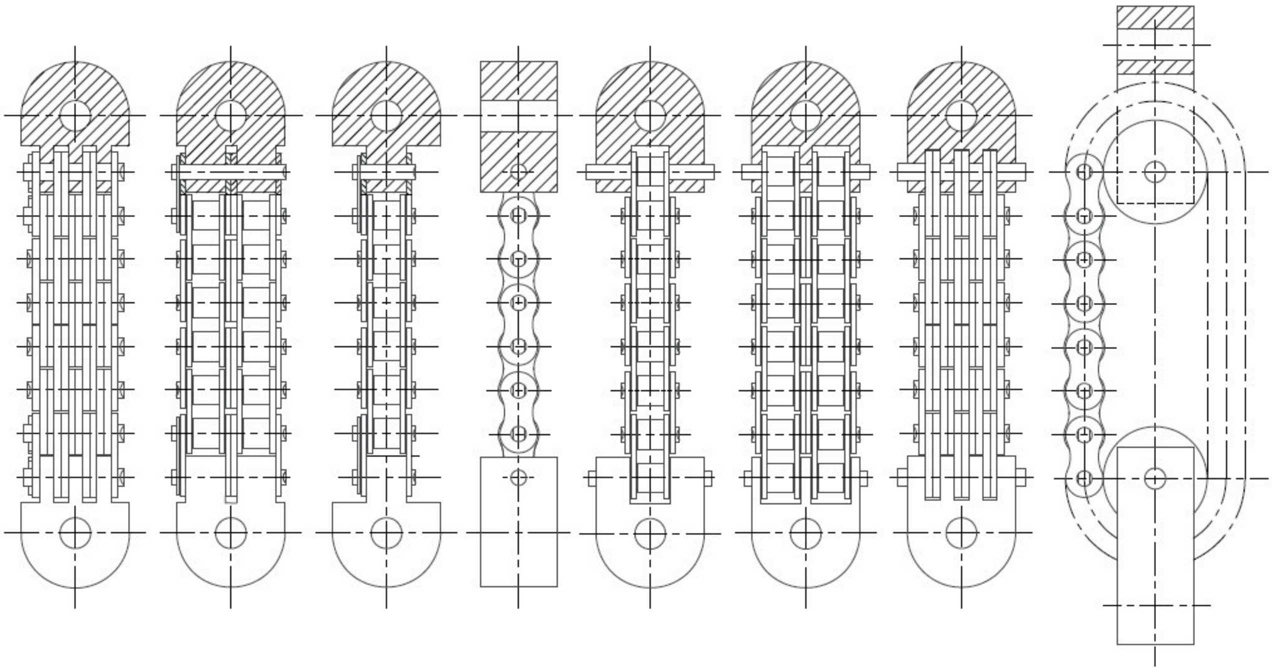
7.1 Test forces

7.1.1 Minimum force

The minimum force for the test shall be at least 1 % but not more than 5 % of the minimum tensile strength given for the subject chain in ISO 606, ISO 10190 or ISO 4347.

7.1.2 Maximum force

The maximum force for the test shall be determined in accordance with 7.2 for a conformity test or in accordance with 7.3 for a staircase test.



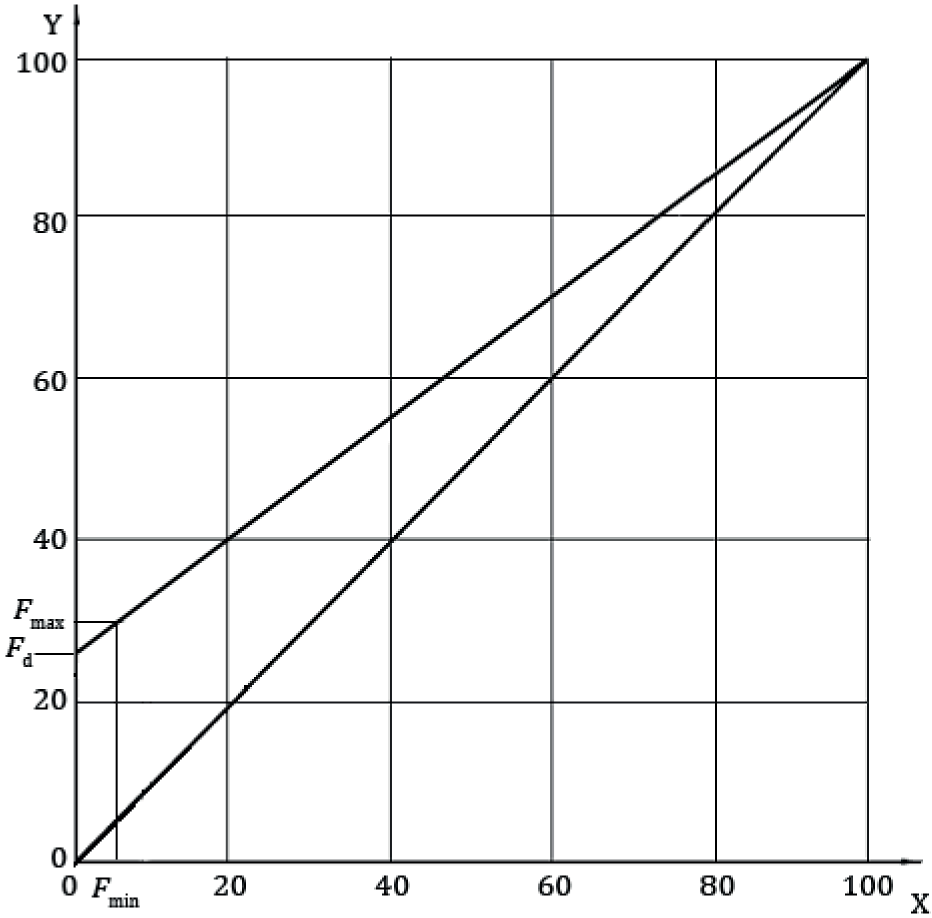
NOTE The endless loop illustration is not applicable to leaf chain.

Figure 2 — Examples of test specimens mounted in universal fixtures

7.1.3 Test force

For analyses of fatigue test data, maximum forces shall be corrected to zero minimum force. A test force is obtained by correcting the maximum force to zero minimum force by means of the Johnson-Goodman method [Formula (3)]. The Johnson-Goodman relationship is illustrated by Figure 3. Here F_{min} is 0,05 × F_u and F_{max} is 0,3 × F_u, and the resulting F_d is 0,263 2 × F_u.

$$F_d = \frac{F_u \left(F_{max} - F_{min}\right)}{F_u - F_{min}} \quad (3)$$



Key

X minimum force, % of F_u

Y maximum force, % of F_u

Figure 3 — Johnson-Goodman diagram

7.1.4 Force application

A longitudinal tensile force shall be applied, sinusoidally varying between the minimum test force determined according to 7.1.1 and the maximum test force determined according to 7.1.2. The test shall continue to endurance or until the specimen fails, whichever is sooner.

7.2 Conformity test

7.2.1 Purpose

The purpose of this test is to determine whether or not a chain meets the dynamic strength requirements given for it in ISO 606, ISO 10190 or ISO 4347.

7.2.2 Endurance

Endurance shall be 3×10^6 cycles.

7.2.3 Minimum test force

The minimum force for the test shall be set in accordance with 7.1.1.

7.2.4 Maximum test force

The maximum test force shall be determined using Formula (4):

$$F_{max} = \frac{F_d F_u + \left[F_{min} \left(F_u - F_d \right) \right]}{F_u} \tag{4}$$

7.2.5 Number of tests

Three specimens shall be tested.

7.2.6 Acceptance

All specimens shall survive to endurance without failure.

7.3 Staircase test

7.3.1 Purpose

The purpose of this test is to determine the fatigue limit of the subject chain.

7.3.2 Description

For the purposes of this International Standard, a staircase test is one in which specimens are tested sequentially at predetermined, equally spaced force levels. The first specimen is tested at a force level slightly greater than the estimated mean fatigue strength of the chain. If the first specimen runs to endurance (runs out), the next specimen is tested at the next higher predetermined force level. If the first specimen fails before endurance, the next specimen is tested at the next lower predetermined force level. Force levels for subsequent tests are determined in the same manner, and the testing continues until the required number of tests are completed.

7.3.3 Endurance

Endurance shall be 10^7 cycles when testing for fatigue limit.

7.3.4 Rules for conducting a staircase test

The test shall begin with a response reversal, then a run-out followed by a failure, or a failure followed by a run-out. The test shall have at least 10 data points to determine the mean with 95 % confidence and six data points to determine the mean with 90 % confidence. It shall have the minimum number of data points in accordance with Table 2 to detect a difference in the mean of approximately one-half step size.

Table 2 — Required sample sizes

Confidence	3-step staircase	4-step staircase	5-step staircase
90 %	6	11	16
95 %	10	15	20

The highest force level in a staircase shall contain only failures.

The lowest force level in a staircase shall contain only run-outs.

Intermediate force levels in a staircase shall contain both failures and run-outs.

7.3.5 Determining step size

7.3.5.1 Using survival test with Probit analysis

See Annex A. The step size shall be determined in accordance with A.5.

7.3.5.2 Using combined test method (CTM)

See Annex B. The step size shall be determined in accordance with B.3.4.3 [see Formula (B.10)].

7.3.5.3 Using empirical method

Extensive testing has shown that reliable results can be obtained when the step size, expressed in newtons (N), is set according to Formula (5) or (6):

For simplex roller chains: $d \approx 14p^{1,5}$ (5)

For multiplex roller chains: $d \approx 0,7 \cdot n_s \cdot 14 \cdot p^{1,5}$ (6)

Where: n_S = number of strands, and n_S is 2 or more.

NOTE When the combined method is used the step size should be determined in accordance with B.3.4.3. There is no established empirical method applicable to leaf chains, so step size should be determined in accordance with that shown in Formula (7). It should be noted that this formula is shown for informative purposes and is for the convenience of deducing an approximate minimum dynamic strength.

$$d \approx f_L \cdot \frac{n_L}{4} \cdot 14 \cdot p^{1,5} \quad (7)$$

where

- p is the chain pitch in mm;
- f_L is lacing factor, according to ISO 4347:2015, Table A.2;
- n_L is total number of plates in adjacent links, e.g. n_L = 10 for 4 × 6 combination.

8 Staircase test data analysis

8.1 Data

The data for a staircase test analysis shall be gathered in accordance with 7.3.

An additional test point at the end of a staircase test can be determined by the rules for conducting a staircase test (see 7.3). This additional test point, sometimes called a “phantom” point, shall be included in the analysis.

8.2 Plotting staircase data

It is customary to tabulate and plot the data as a staircase test progresses to ensure that the rules for constructing a staircase are followed. An example of such a data plot (three levels and 95 % confidence level) is shown in Table 3.

Table 3 — Staircase data plot — Example

Test force	Invalid tests		Valid tests									
$F_d + 2d$	X											
$F_d + d$		X						X		X		#
F_d			X		X		O		O		O	
$F_d - d$				O		O						
O = Run-Out; X = Failure; # = Phantom Point.												

8.3 Statistical calculations

8.3.1 Mean fatigue strength: 0,50 probability of survival

The mean fatigue strength shall be calculated using Formula (8),

$$F_b = \frac{\sum_{i=1}^{n} F_{d_i}}{n} \tag{8}$$

where n is the total number of valid tests in the staircase calculations.

8.3.2 Standard deviations

The standard deviations of the staircase data shall be calculated using Formula (9),

$$S = \left[\frac{\sum_{i=1}^{n} F_{d_i}^2}{n} - F_b^2 \right]^{0.5} \tag{9}$$

8.3.3 Fatigue limit: 0,998 65 probability of survival

The fatigue limit shall be calculated using Formula (10),

$$F_{dx} = F_b - 3S + d \tag{10}$$

9 Report of test results

9.1 Test chain information

The originator shall provide to the user

a) the brand name or other identifying name or mark of the test chain,

b) the ISO number or manufacturer's number and the pitch of the test chain, and

c) the length in free pitches of the test specimens.

9.2 Test equipment and procedures

9.2.1 Test equipment

The originator shall provide to the user

a) the brand name and type of testing machine,

b) the maximum rated capacity of the test machine,

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

d) the method of dynamic force verification and monitoring, and

e) the method of calibration and the most recent date calibrated.

9.2.2 Test procedures

The originator shall provide to the user

a) the type of test; conformity or staircase,

b) the number of cycles to endurance, and

c) any ambient conditions that could affect the test results.

9.3 Test results for conformity and staircase tests

The originator shall provide a table of test results to the user, which shall include

a) identification of the test specimen,

b) the test sequence, the order in which the specimens were run,

c) the maximum and minimum force for each test,

d) the test force, corrected to zero minimum force, for each test,

e) the force cycling frequency,

f) the number of cycles at which each test was terminated,

g) the reason each test was terminated and, if a failure, the component of the chain that failed,

h) a brief summary of the post-test examination, if any, and

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

For a staircase test, the originator shall also provide the user with

— the mean fatigue strength, F_b, and

— the minimum fatigue strength, or fatigue limit.

Annex A
(informative)

Survival test with abridged Probit analysis

A.1 Principle

The purpose of this test is to determine the mean fatigue limit and its standard deviation. A survival test with abridged Probit analysis can also be used to determine the step size for future staircase testing of the subject chain model.

A.2 Description

The survival test is a procedure in which groups of chain specimens are tested at different force levels such that the central force level contains approximately 50 % failures, the highest force level contains 90 % to 95 % failures, and the lowest force level contains 5 % to 10 % failures.

The Probit analysis is used to estimate the mean fatigue limit and standard deviation of the tested population. The step size is then set equal to between 67 % and 150 % of the standard deviation for future staircase testing of the subject chain model.

A.3 Test procedure

A.3.1 Test specimens

Prepare at least 50, and preferably 100, test specimens in accordance with Clause 6, with all test specimens from the same production batch.

Provide additional test specimens for preliminary or invalid tests.

A.3.2 Endurance

Set endurance at 10^7 cycles.

A.3.3 Force levels

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

Ensure that the interval between adjacent force levels is uniform.

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

A.3.4 Testing

Allocate test specimens to each level according to Table A.1 or Table A.2 in order to make the precision at each force level comparable. At least five specimens at each level, and 50 specimens in total, are required for acceptable accuracy.

Table A.1 — Allocation of test specimens for five force levels

Expected run-out %	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 A.2 — Allocation of test specimens for four force levels

Expected run-out %	Relative group size
20 to 80	1,0
5 to 10 or 90 to 95	2,5

Test each specimen until it fails or reaches endurance.

— Central force level: approximately 50 % failures.

— Highest force level: at least one run-out.

— Lowest force level: at least one failure.

A.4 Analysis procedure

A.4.1 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 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 of this International Standard.

A.4.2 Distributions

Visually check the distributions of survival (cycles to failure) and force by means of a probability plot and confirm that the distribution of cycles to failure at the central and each higher force level is log-normal and that of survival across the force levels is normal.

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

A.4.3 Standard deviation

Estimate the standard deviation of the survival test data, S, which is also the slope of the regression line, using Formula (A.1).

$$S = \left| \frac{n_F \Sigma XY - \Sigma X \Sigma Y}{n_F \Sigma X^2 - (\Sigma X)^2} \right| \tag{A.1}$$

where

n_F is the number of force levels in the test;

X is the survival probability, in standard normal transform units, Z (see Figure A.1);

Y is the test force, in newtons (N).

A.4.4 Mean fatigue limit

Estimate the mean fatigue limit of the survival test data, Y_0, which is also the Y-intercept (of force with 50 % survival), using Formula (A.2).

$$Y_0 = \frac{\Sigma Y + S \Sigma X}{n_F} \tag{A.2}$$

A.5 Step size

Set the step size for subsequent staircase testing at 67 % to 150 % of the standard deviation. The step size should be set nearly equal to 100 % of the standard deviation.

A.6 Example

A survival test was conducted with specimens of 80 chain tested at six force 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 force levels are shown in Table A.3.

Table A.3 — Test results

Force level kN	Number of test specimens	Failures	Run-out
19,45	25	23	2
17,60	10	6	4
15,75	10	4	6
13,90	25	1	24

A table usually is created for the survival test data and preliminary calculations. Table A.4 was created for this example.

Table A.4 — Survival test data and Probit analysis

Number of test specimens	X	Survival %	Z	Force, *F* kN	*X*	*Y*	X^2	Y^2	*(XY)*
25	1	96,00	1,751	13,900	1,751	13,90	3,0660	193,2	24,34
10	4	60,00	0,253	15,750	0,253	15,75	0,0640	248,1	3,98
10	6	40,00	−0,253	17,600	−0,253	17,60	0,0640	309,8	−4,45
25	23	8,00	−1,405	19,450	−1,405	19,45	1,9740	378,3	−27,33
				Totals	**0,346**	**66,70**	**5,168**	**1129,3**	**−3,46**

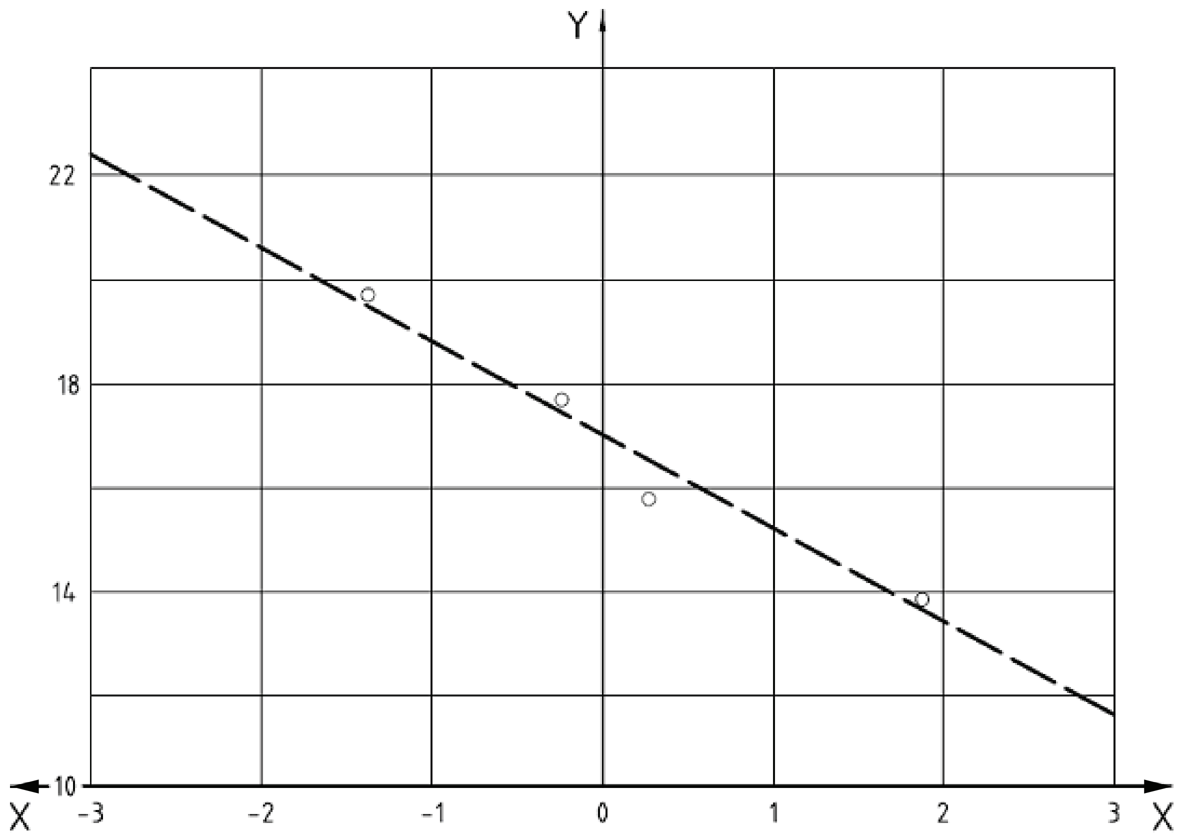
From this data, the calculated standard deviation was

$$S = \left| \frac{4(-3,46) - (0,346 \times 66,70)}{4 \times 5,168 - 0,346^2} \right| = 1,796\,\text{kN} \qquad \text{(A.3)}$$

and the mean fatigue limit

$$Y_0 = \left| \frac{66,70 + (1,796 \times 0,346)}{4} \right| = 16,83\,\text{kN} \qquad \text{(A.4)}$$

The results of this analysis with four force levels n_F are plotted in Figure A.1.



Key

X survival probability, standard normal transform units, *Z*

Y force, *F*, kN

Figure A.1 — Probit analysis

Annex B
(informative)

Combined test methods

B.1 Purpose

The purpose of this test is to determine the slope of the *F*–*N* line and the fatigue limit of a particular chain in a single test series. The CTM also can be used to determine the step size for future staircase testing of the subject chain model.

B.2 Description

Numbers of test specimens in the CTM are determined by the different probabilities of survival, *R*, of the mean *F*–*N* line. The 14 *F*–*N* test method for determining $R = 90$ %, and the 24 *F*–*N* test method for determining $R = 95$ %, are described here. The 14 *F*–*N* test method is a procedure in which eight chain specimens are tested at four force levels in the finite life range, and five specimens plus one phantom data are tested in a staircase. The 24 *F*–*N* test method is a procedure in which 14 chain specimens are tested at four force levels in the finite life range, and nine specimens plus one phantom data are tested in a staircase. The mean *F*–*N* line and the standard deviation of fatigue life are determined by statistical calculation. The standard deviation of force in a staircase is derived from the standard deviation of fatigue life in a finite life range, and is the step size for the staircase test

B.3 Test procedure

B.3.1 Test specimens

Prepare at least 13 test specimens for the 14 *F*–*N* test method, or 23 test specimens for the 24 *F*–*N* test method, in accordance with Clause 6, with all test specimens from the same production batch. Provide additional test specimens for preliminary or invalid tests.

B.3.2 Endurance

For the staircase portion of the test, set endurance at 10^7 cycles. If endurance is set between 3×10^6 and 10^7 cycles, extrapolate the results to 10^7 cycles by the method given in Annex G.

B.3.3 Force levels

For the finite life portion of the test, establish four test force levels F_A, F_B, F_C, and F_D in accordance with B.3.4.1.

For the staircase portion of the test, an initial test force level, F_1, might be set at the force of two steps plus the force where the mean *F*–*N* line intersects 10^6 cycles, with additional test force levels in increments of the step size.

B.3.4 Testing

B.3.4.1 Preliminary tests

Test one specimen at the lowest force level (F_D) in the finite life portion. If the measured fatigue life departs significantly from the 5×10^5 cycles, test an additional specimen at an adjusted force level. When the resulting fatigue life is near 5×10^5 cycles, use that force level as (F_D). Then test one specimen at the highest force level (F_A) in the finite life portion, with this highest force level set at no more than 60 % of the minimum tensile strength in ISO 606, ISO 10190 or ISO 4347. Calculate the other test force values using Formulae (B.1) to (B.3).

$$\Delta = \frac{F_A - F_D}{3} \tag{B.1}$$

$$F_B = F_A - \Delta \tag{B.2}$$

$$F_C = F_A - 2\Delta \tag{B.3}$$

B.3.4.2 Finite life tests

For the 14 *F*–*N* test method, complete the finite life portion of the test by testing a total of two specimens at each force levels. For the 24 *F*–*N* test method, complete the finite life portion of the test by testing a total of four specimens at force levels F_A and F_B, and three specimens at force levels F_C and F_D. Determine the equation for the *F*–*N* line using Formulae (B.4) to (B.8). Calculate the standard deviation of logarithmic life using Formula (B.9). Derive the standard deviation of force using Formula (B.10).

B.3.4.3 Staircase tests

The step size for the staircase test should be equal to the calculated standard deviation of force determined by Formula (B.10). Conduct a six-test staircase test (five valid test points plus one phantom point) for the 14 *F*–*N* test method, or a 10-test staircase test (nine valid test points plus one phantom point) for the 24 *F*–*N* test method, in accordance with 7.3.

B.4 Analysis procedure

B.4.1 Finite life portion

In the CTM, fatigue life is plotted on a logarithmic scale and force is plotted on a linear scale. The *F*–*N* line, standard deviation of logarithmic life, and standard deviation of force are determined from Formulae (B.4) to (B.10).

The regression equations for the *F*–*N* line are

$$\lg N = \hat{\alpha} + \hat{\beta} F_d \tag{B.4}$$

$$\hat{\alpha} = \overline{\lg N} - \hat{\beta}\overline{F}_d \tag{B.5}$$

$$\hat{\beta} = \frac{\sum_{i=1}^{n_f}\left(F_{d_i} - \overline{F}_d\right)\left(\lg N_i - \overline{\lg N}\right)}{\sum_{i=1}^{n_f}\left(F_{d_i} - \overline{F}_d\right)^2} \tag{B.6}$$

$$\overline{\lg N} = \frac{1}{n_f}\sum_{i=1}^{n_f} \lg N_i \tag{B.7}$$

$$\bar{F}_{\mathrm{d}} = \frac{1}{n_f} \sum_{i=1}^{n_f} F_{\mathrm{d}_i} \qquad \text{(B.8)}$$

Where the number of tests, n_f, are 8 for the 14 *F–N* test method, and 14 for the 24 *F–N* test method.

The estimated standard deviation of logarithmic life is

$$\hat{\sigma}_{\lg N} = \sqrt{\frac{1}{n_{\mathrm{f}} - 2} \sum_{i=1}^{n_{\mathrm{f}}} \left[\lg N_i - \left(\hat{\alpha} + \hat{\beta} F_{\mathrm{d}_i} \right) \right]^2} \qquad \text{(B.9)}$$

The estimated standard deviation of force is

$$\hat{\sigma}_F = \frac{1}{\left|\hat{\beta}\right|} \hat{\sigma}_{\lg N} \qquad \text{(B.10)}$$

B.4.2 Staircase portion

The estimated mean fatigue strength F_{b} is:

$$F_{\mathrm{b}} = \frac{1}{n_s} \sum_{j=1}^{n_s} F_{\mathrm{d}_j} \qquad \text{(B.11)}$$

where the number of tests, n_s, are 6 for the 14 *F–N* method, and 10 for the 24 *F–N* method.

The standard deviations of fatigue strength should be calculated using Formula (7) (see 8.3.2).

B.5 *R–F–N* curve

The mean *R–F–N* curve, at *R* = 50 % probability of survival, is defined by Formula (B.4) for the finite life area, and by Formula (B.11) for endurance at the staircase test area.

Using data collected by the 14 *F–N* test method, the *R–F–N* curve, at *R* = 90 % probability of survival, is defined by Formula (B.12) for the finite life area, and Formula (B.13) for endurance at the staircase test area. The value of *q* is 1,28.

Using data collected by the 24 *F–N* test method, the *R–F–N* curve, at *R* = 95 % probability of survival, is defined by Formula (B.12) for the finite life area, and Formula (B.13) for endurance at the staircase test area. The value of *q* is 1,64.

For either case, extrapolate the fatigue limit to 10^7 cycles using the method given in Annex G, link this point with the point at endurance, and extend that line to connect to a line at the finite life area.

$$\lg N = \hat{\alpha} + \hat{\beta} F_{\mathrm{d}} - q \hat{\sigma}_{\lg N} \qquad \text{(B.12)}$$

$$F_{0{,}90 \text{ or } 0{,}95} = F_b - \frac{q}{\left|\hat{\beta}\right|} \hat{\sigma}_{\lg N} \qquad \text{(B.13)}$$

B.6 Sample test report and graph

Fatigue Test Report

Report No.: 1001 Page 1 of 2 Report Date: 2011-06-10

Chain:

Brand	Number	Pitch	Specimen Length	Other	Minimum dynamic Specification
ABC Chain	80	25,4 mm	5P, ILEE		

Mechanical Properties
Not Taken

Test:

Type	Endurance	Temperature	Other
Combined (24 *F-N*)	3×10^6 Cycles	Approx. 20 °C	Moderate Humidity

Machine:

Brand	Type	No. Used	Calibration Date	Force Verification and Monitoring
XYZ	Servo-hydraulic	1	2011-05-20	Periodic, Strain-gauge bar

Date	Test No.	Frequency Hz	F_{max} kN	F_{min} kN	F_d kN	Cycles N	Failure	Remarks
11-06-05	001	13	33,3	1,80	32,55	7,055E4	IP	
11-06-05	002	13	24,9	1,80	23,87	2,381E5	IP	
11-06-05	003	13	30,5	1,80	29,66	1,104E5	IP	
11-06-06	004	13	30,5	1,80	29,66	8,980E4	IP	
11-06-06	005	13	24,9	1,80	23,87	2,510E5	IP	
11-06-06	006	13	27,7	1,80	26,77	2,236E5	IP	
11-06-07	007	13	33,3	1,80	32,55	9,895E4	IP	
11-06-07	008	13	24,9	1,80	23,87	2,885E5	IP	
11-06-08	009	13	33,3	1,80	32,55	6,891E4	IP	
11-06-08	010	13	33,3	1,80	32,55	6,036E4	IP	
11-06-08	011	13	30,5	1,80	29,66	9,309E4	IP	
11-06-09	012	13	30,5	1,80	29,66	1,242E5	IP	
11-06-09	013	13	27,7	1,80	26,77	1,905E5	IP	
11-06-09	014	13	27,7	1,80	26,77	2,379E5	IP	

Results and Conclusions:

$\alpha = 7,07$

$\beta = -0,07$

$\sigma_{\lg N} = 0,081$

$\sigma_F (s) = 1,188$

The results of the finite-life portion tests are plotted on the attached graph [see Figure B.1].

Signed: *John Smith*

Fatigue Test Report

Report No.: 1001 Page 2 of 2 Report Date: 2011-06-22

Chain:

Brand	Number	Pitch	Specimen Length	Other	Minimum dynamic Specification
ABC Chain	80	25,4 mm	5P, ILEE		

Mechanical Properties

Not Taken

Test:

Type	Endurance	Temperature	Other
Combined (24 *F-N*)	3 × 10^6 Cycles	Approx. 20 °C	Moderate Humidity

Machine:

Brand	Type	No. Used	Calibration Date	Force Verification and Monitoring
XYZ	Servo-hydraulic	1	2011-05-20	Periodic, Strain-gauge bar

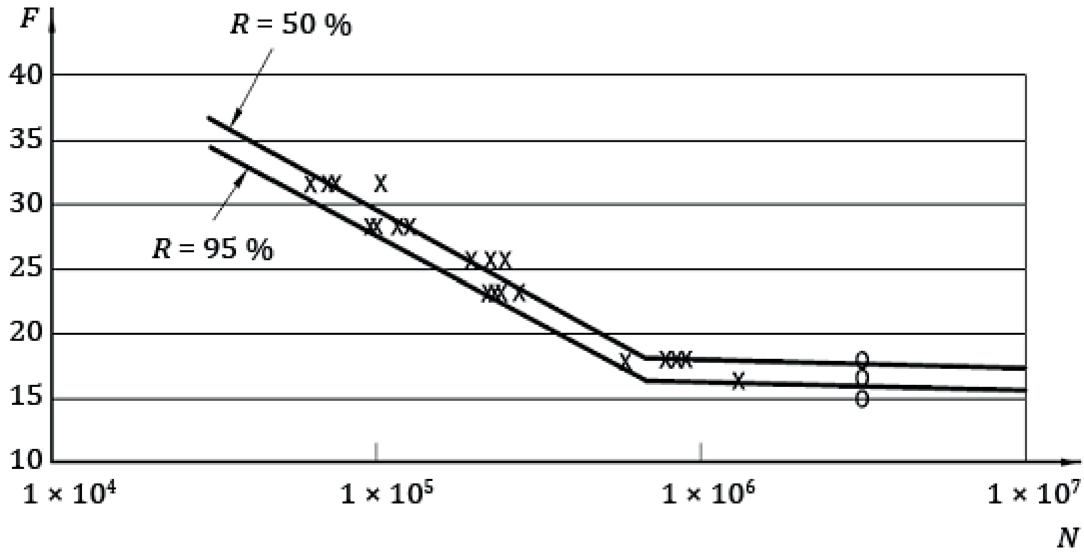
Date	Test No.	Frequency Hz	F_{max} kN	F_{min} kN	F_d kN	Cycles N	Failure	Remarks
11-06-12	015	13	19,6	1,80	18,40	8,471E5	IP	
11-06-12	016	13	18,4	1,80	17,16	3,000E6	NF	
11-06-13	017	13	19,6	1,80	18,40	5,581E5	IP	
11-06-13	018	13	18,4	1,80	17,16	1,240E6	IP	
11-06-16	019	13	17,2	1,80	15,92	3,000E6	NF	
11-06-19	020	13	18,4	1,80	17,16	3,000E6	NF	
11-06-19	021	13	19,6	1,80	18,40	8,124E5	IP	
11-06-20	022	13	18,4	1,80	17,16	3,000E6	NF	
11-06-21	023	13	19,6	1,80	18,40	3,000E6	NF	
	024		20,8	1,80	19,64			Phantom Point

Results and Conclusions:

F_d	Staircase	Histogram		
19,64	#	#	F_b	= 17,78 kN
18,40	X X X O	XXXO	σ_F	= 1,000 kN
17,16	O X O O	OXOO	$F_{0,95}$	= 16,02 kN (at 3 × 10^6 cycles)
15,92	O	O	$F_{0,95}$	= 15,35 kN (at 10^7 cycles)

The results of the finite-life portion tests are plotted on the attached graph [see Figure B.1].

Signed: John Smith



Key

F force, kN

N combined cycles to failure

R probability of survival

NOTE Diagram is not to scale.

Figure B.1 — Sample CTM test results

Annex C
(informative)

Justification for adding one step to fatigue limit in staircase analysis

C.1 General

The staircase analyses in this International Standard utilize all test points, both failures and run-outs. The calculated minimum fatigue strength ($F_b - 3S$) is always less than the lowest test force. By definition, all responses at the lowest test force are run-outs. Consequently, the minimum fatigue strength, with a 0,135 % probability of failure, is greater than the lowest test force in all cases.

C.2 Analysis

Staircases, having 50 to 75 tests, were constructed by combining several staircases with 10 tests each. Means and standard deviations were calculated for all tests and failures only in each staircase. Calculations for 50, 80, and 120 chains are presented in Tables C.1 to C.4. A graph of the four-step staircase analysis for 80 chain is shown in Figure C.1.

Table C.1 — Analysis of 50 chain, four-step staircase data

Force (N)	**x**	**o**	$n = 75$	$d = 925$		
8 810	7	0		Analysis of all data points:		
7 885	21	8		$F_b = 7\ 393$	$s = 747$	$F_b - 3s = 5\ 152$
6 960	8	23		Analysis of Failures Only:		
6 035	0	8		$F_b = 7\ 860$	$s = 596$	$F_b - 3s = 6\ 072$
Totals	36	39	1,232 s = 0,995d = Difference = 920			

Table C.2 — Analysis of 80 chain, four-step staircase data

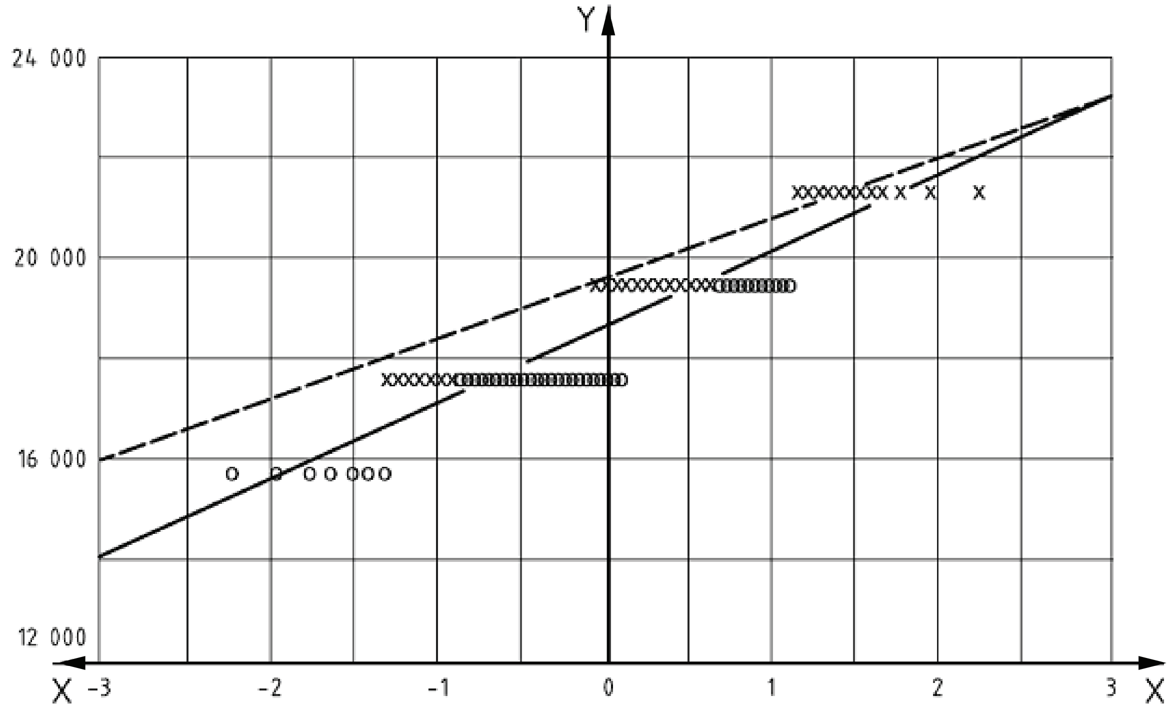
Force (N)	**x**	**o**	$n = 75$	$d = 1\ 855$		
21 315	9	0		Analysis of all data points:		
19 460	21	9		$F_b = 18\ 620$	$s = 1\ 521$	$F_b - 3s = 14\ 057$
17 605	7	22		Analysis of Failures Only:		
15 750	0	7		$F_b = 19\ 563$	$s = 1\ 214$	$F_b - 3s = 15\ 921$
Totals	37	38	1,226 s = 1,005d = Difference = 1 864			

Table C.3 — Analysis of 80 chain, three-step staircase data

Force (N)	**x**	**o**	$n = 50$	$d = 1\ 855$		
21 315	9	0		Analysis of all data points:		
19 460	16	9		$F_b = 19\ 203$	$s = 1\ 286$	$F_b - 3s = 15\ 345$
17 605	0	16		Analysis of Failures Only:		
Totals	25	25		$F_b = 20\ 128$	$s = 890$	$F_b - 3s = 17\ 458$
			1,643 s = 1,139d = Difference = 2 113			

Table C.4 — Analysis of 120 chain, five-step staircase data

Force (N)	**x**	**o**	*n* = 75	*d* = 3 240		
39 350	5	0		Analysis of all data points:		
36 110	14	5		F_b = 32 610	*s* = 3 540	$F_b - 3s$ = 21 990
32 870	11	13		Analysis of Failures Only:		
29 630	9	10		F_b = 34 113	*s* = 3 167	$F_b - 3s$ = 24 612
26 390	0	8	0,741 *s* = 0,809*d* = Difference = 2 622			
Totals	39	36				



Key

Y failure probability, standard normal transform units, *Z*
X force, *F*, N
o run-out
x failures
— distribution, all data
– – distribution, failures only

Figure C.1 — 80 chain fatigue analysis

Analysis of 50 and 80 four-step staircases showed the calculated minimums for failures were 0,99 and 1,00 steps and 1,23 and 1,22 standard deviations higher than the calculated minimums for all tests. Analysis of an 80 three-step staircase showed that the calculated minimum for failures was 1,14 steps and 1,64 standard deviations higher than the calculated minimum for all tests. Analysis of the 120 five-step staircase showed that the calculated minimum for failures was 0,81 of a step and 0,74 of a standard deviation higher than the calculated minimum for all tests.

C.3 Conclusions

The following conclusions can be drawn from the foregoing.

a) The fatigue limit, with 99,865 % survival (0,135 % probability of failure), is one step greater than the minimum fatigue strength calculated from all tests.

b) The three-step and four-step staircase analyses support the first conclusion very well.

c) The five-step staircase analysis does not support the first conclusion very well, probably because of the large variance.

d) The fatigue limit, with 99,865 % survival (0,135 % probability of failure), is one standard deviation greater than the minimum fatigue strength calculated from all test points only when the standard deviation is equal to the step size.

Annex D
(informative)

Adding an additional "phantom" point at the end of staircase test

The rules for selecting the third and subsequent test force levels in a staircase dictate that the next test is to be run at a one-step-higher force level if the test just completed was a run-out, and at a one-step-lower force level if the test just completed was a failure. This permits the force level at which a test would be run after the final actual test in a staircase to be determined. Consequently, one data point might be added to the staircase series, after the final test point, even though a test at that point was not actually run.

The procedure is as follows: if the final test was a run-out, add a "phantom" point at one step higher test load; if the final test was a failure, add a phantom point 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.

Annex E
(informative)

Reporting fatigue test results

E.1 General

This Annex suggests ways of presenting the results of roller chain and leaf chains fatigue tests, and presents both tabular and graphical methods. Sample fatigue test report forms are presented and explained, and sample graphical methods of presenting fatigue test results are given.

E.2 Tabular presentation of results

This Clause presents a format for reporting (see also Annex B, Annex E and Annex H) the required data from 9.1, 9.2 and 9.3, and gives a brief description of each item of information that might be entered in the appropriate space of this fatigue test report, keyed to the (here) numbered spaces on the form (unnumbered spaces not being in need of explanation).

Fatigue Test Report

Report No.: Report Date:

Chain:

Brand	Number	Pitch	Specimen Length	Other	Minimum dynamic Specification (optional)
(1)	(2)	(3)	(4)	(5)	(6)

Mechanical Properties

(7)

Test:

Type	Endurance	Temperature	Other
(8)	(9)	(10)	(11)

Machine:

Brand	Type	No. Used	Calibration Date	Force Verification and Monitoring
(12)	(13)	(14)	(15)	(16)

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_d kN	**Cycles** N	**Failure**	**Remarks**
(17)	(18)	(19)	(20)	(21)	(22)	(23)	(24)	(25)

Results and Conclusions:

(26)

Signed: (27)

Key to Fatigue Test Report Form

1 brand name or other identifying name or mark of the tested chain

2 ISO number or manufacturer's number of the chain

3 nominal pitch of the chain

4 length of test specimens, in free pitches [a]

5 other characteristics of the test chain that might be helpful (production batch identity, experimental chain designation, or non-standard design features)

6 minimum dynamic specification is optional

7 results of tensile tests, or bush and pin press out force tests

8 type of test; conformity, staircase, survival, combined method, or finite life

9 declared endurance, in number of cycles, for a conformity, staircase, survival, or combined method test

10 mean ambient temperature, or range of minimum and maximum temperatures, during test

11 other environmental conditions (high humidity, etc.) that might affect test results

12 brand name or other identifying name or mark of the testing machine

13 type (harmonic spring, servo-hydraulic, electro-magnetic, etc.) of testing machine

14 the number of machine used

15 date on which the machine was last calibrated

16 dynamometer and transducer used to verify and monitor the test force [b]

17 date the individual test was completed

18 sequence number of the test [c]

19 frequency at which the fluctuating force was applied

20 maximum value of the fluctuating force (see Clause 3)

21 minimum value of the fluctuating force (see Clause 3)

22 test force, corrected to zero minimum force (see Clause 3)

23 number of cycles at which the test ended

24 component that failed — inner plate (IP), outer plate (OP), Pin (PIN), or intermediate plate (ITP) [d]

25 any unique notes concerning the test, e.g. if a terminal connector link failed and was replaced during the test, it should be noted

26 results and conclusions [e]

27 signature

a A note of inner link, each end (ILEE); outer link, each end (OLEE); or endless should also be given here.

b There also should be a note as to whether the monitoring was periodic or continuous, and whether or not there was feedback control.

c This may also be combined with machine reference number, if more than one testing machine was used.

d If the test ran-out, “No Failure” (NF) may be entered.

e For a conformity test, the information required by 9.3, and a statement of “Accepted” or “Not Accepted”, explaining failure, if possible; for a staircase test, the information required by 9.3, and any supplemental information that might be helpful to the user; for a combined method test, the information required by Annex B, and any supplemental information that might be helpful to the user; for a finite life method test, the information required by Annex H, and any supplemental information that might be helpful to the user.

E.3 Graphical presentation, suggested forms

E.3.1 General

If sufficient data are generated, and the user so requests, the originator should present fatigue test results in a graphical form. Usually, only a combined test, a finite life test, or a finite life test paired with a staircase test on the same batch of chain, generates data suitable for graphical presentation.

E.3.2 Types of graph

The most common graphical methods of presenting fatigue test data are the *F*-Log *N* and Log *F*-Log *N* plots. The dependent variable (fatigue life in cycles) is plotted on the abscissa, a logarithmic scale. The independent variable (test force in kilonewtons), is plotted on the ordinate, an arithmetic or logarithmic scale.

E.3.3 *F*-Log *N* graph

In this presentation, force is assigned an arithmetic scale and life is assigned a logarithmic scale. A typical *F*-Log *N* plot for a finite life test is shown in Annex H.

The failures (x) from finite life tests or staircase tests should be plotted on the test force level at the number of cycles at which failure occurred. The run-out (o) from staircase tests should be plotted on the test force level at the predetermined number of cycles for endurance. When there are multiple run-outs at the same force level, the number of run-outs should be noted just to the right of the symbol.

Transmission chain and leaf chain fatigue test results are acceptably represented by two-segment straight lines. One is a horizontal, or a nearly horizontal, line extending from the fatigue strength at 10^7 cycles to the fatigue strength at 10^6 cycles, at a slope determined by the procedure described in Annex G. The other is a regression line extending from the fatigue strength at 10^6 cycles to the fatigue strength at approximately 10^4 cycles, calculated from finite life test data as described in Annex H.

All test data points should be plotted on graphs along with calculated or constructed regression lines.

E.3.4 Log *F*-Log *N* graph

In this presentation, both force and life are assigned a logarithmic scale. A typical Log *F*-Log *N* plot is shown in the sample form presented in E.4.

The failures (x) from finite life tests or staircase tests should be plotted on the test force level at the number of cycles at which failure occurred. The run-outs (o) from staircase tests should be plotted on the test force level at the predetermined number of cycles for endurance. When there are multiple run-outs at the same force level, the number of run-outs should be noted just to the right of the symbol. The failures (x) and run-outs (o) should be plotted as shown in the graph in Figure E.1.

The slope of the regression line, extending from the fatigue strength at 10^7 cycles to the fatigue strength at 10^6 cycles, is determined by the procedure described in Annex G. The other regression line, extending from the fatigue strength at 10^6 cycles to the fatigue strength at 10^4cycles, is calculated from finite life test data as described in Annex H.

All test data points should be plotted on graphs along with calculated regression lines.

E.4 Sample test reports

A staircase test and a finite life test were conducted on one batch of "BCD Chain" Company's number 80 chain. Results of the staircase test are presented in the following sample test report. Results of the finite life test are given in Annex H. The results of the sample staircase test are shown together with the results of the finite life test from Annex H on the graph of Figure E.1.

NOTE A combined test was conducted on one batch of "ABC Chain" Company's number 80 chain. The results of that sample test are presented in Annex B.

A conformity test was also conducted on a batch of "BCD Chain" Company's number 80 chain. The results of that test are given in the sample test report concluding this Annex.

Fatigue Test Report

Report No.: 1002 Page 1 of 1 Report Date: 2011-09-30

Chain:

Brand	Number	Pitch	Specimen Length	Other	Minimum dynamic Specification
BCD Chain	80	25,4 mm	13P, ILEE		

Mechanical Properties

Not Taken

Test:

Type	Endurance	Temperature	Other
Combined (24 *F-N*)	10^7 Cycles	Approx. 20 °C	Moderate humidity

Machine:

Brand	Type	No. Used	Calibration Date	Force Verification and Monitoring
XYZ	Mech., Harmonic Spring	1	2011-08-23	Periodic, Strain-gauge bar

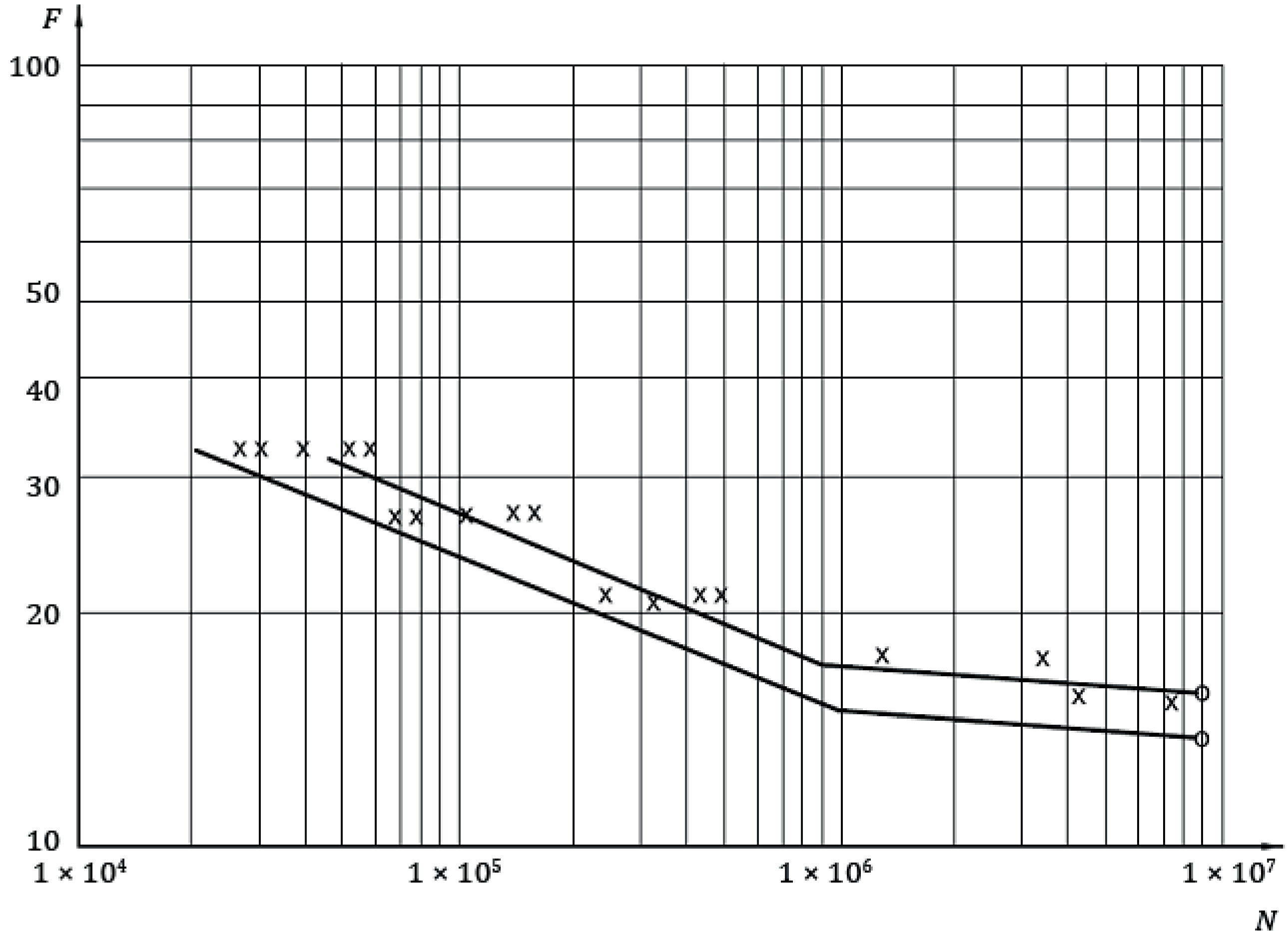
Date	Test No.	Frequency Hz	F_{max} kN	F_{min} kN	F_d kN	Cycles N	Failure	Remarks
11-09-20	001	31	17,35	2,224	15,75	4,771E6	IP	
11-09-23	002	31	15,57	2,224	13,90	1,000E7	NF	
11-09-23	003	31	17,35	2,224	15,75	1,000E7	NF	
11-09-24	004	31	19,12	2,224	17,60	4,096E6	IP	
11-09-24	005	31	17,35	2,224	15,75	8,480E6	IP	
11-09-25	006	31	15,57	2,224	13,90	1,000E7	NF	
11-09-25	007	31	17,35	2,224	15,75	1,000E7	NF	
11-09-25	008	31	19,12	2,224	17,60	1,463E6	IP	
11-09-26	009	31	17,35	2,224	15,75	1,000E7	NF	
11-09-26	010		19,12	2,224	17,60			Phantom Point

Results and Conclusions:

F_d	Staircase							Histogram		
17,60			X			X	#	XX#	F_b	= 17,78 kN
15,75	X	O	X		O	O		XOXOO	σ_F	= 1,188 kN
13,90	O			O				OO	$F_{dx,0,99865}$	$= F_b - 3\sigma + d$ = 13,90 kN

The results of the finite-life portion tests are plotted on the attached graph [see Figure E.1].

Signed: John Smith



Key

F force, kN

N life, cycles

Figure E.1 — Graph of sample staircase test and finite life test for a 80 chain (Log *F*/Log *N* plot)

Fatigue Test Report

Report No.: 1003 Page 1 of 1 Report Date: 2011-09-27

Chain:

Brand	Number	Pitch	Specimen Length	Other	Minimum dynamic Specification
BCD Chain	80	25,4 mm	13P, ILEE		9,55 kN

Mechanical Properties

Not Taken

Test:

Type	Endurance	Temperature	Other
Conformity	3×10^6 Cycles	Approx. 20 °C	Moderate humidity

Machine:

Brand	Type	No. Used	Calibration Date	Force Verification and Monitoring
XYZ	Mech., Harmonic Spring	1	2011-08-23	Periodic, Strain-gauge bar

Date	**Test No.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_d kN	**Cycles** N	**Failure**	**Remarks**
11-09-20	026	31	11,39	2,224	9,55	3,000E6	NF	
11-09-23	027	31	11,39	2,224	9,55	3,000E6	NF	
11-09-23	028	31	11,39	2,224	9,55	3,000E6	NF	

Results and Conclusions:

Accepted.

Signed: John Smith

Annex F
(informative)

Establishing chain application fatigue ratings

F.1 Overview

This International Standard specifies procedures for determining the fatigue limit of transmission chains and leaf 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 10-test staircase. In actual applications, the chain length usually is between 50 and 250 pitches, the chains used might be from several production batches, and the total production volume greatly exceeds that represented by only six or 10 tests. Additional analysis methods clearly are needed to evaluate the differences between specified laboratory conditions and actual applications.

This Annex presents possible methods for evaluating some of the differences between a chain's fatigue limit under specific laboratory conditions and that chain's fatigue rating for a variety of applications. Neither it nor this International Standard as a whole prescribes a method for establishing chain application fatigue ratings.

Instead, this Annex describes some methods that can 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 specimen length and a much longer transmission chain (or leaf chain) length, the production quantity represented by a six-test or 10-test sample and a much larger production quantity, and one production batch and many production batches. Some other factors that should be considered are mentioned, but methods to evaluate them are beyond the scope of this Annex. There also may be factors that should be considered that are not mentioned in this Annex.

F.2 Methods

F.2.1 Chain length

One method for evaluating the effect of difference between test specimen length and transmission chain (or leaf chain) length follows.

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

$$A^N = 0{,}50 \tag{F.1}$$

Similarly, for $F_{b(-3SN)}$ to be the −3σ of N values:

$$A^N = 0{,}998\ 65 \tag{F.2}$$

For the purposes of this Annex, 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 transmission chain (or leaf chain). Calculated values of A^N, for selected values of N, are given in Table F.1 and shown in Figure F.1.

Then:

$$F_{bN} = F_{b1} - Z_{(A,Fb)}\, S_P \qquad (F.3)$$

where

F_{bN} is the median (mean) fatigue strength of a sample of chains, each with N inner link apertures;

F_{b1} is the median (mean) fatigue strength of a sample of chains, each with one inner link aperture;

$Z_{(A,Fb)}$ is the standard normal transform corresponding to A^N and F_{bN};

S_P is the estimated standard deviation of population when $N = 1$.

and

$$F_{b(-3SN)} = F_{b1} - Z_{(A,-3\sigma)}\, S_P \qquad (F.4)$$

where

$F_{b(-3SN)}$ is the minimum ($-3S$) fatigue strength of a sample of chains, each with N inner link apertures;

F_{b1} is the median (mean) fatigue strength of a sample of chains, each with one inner link aperture;

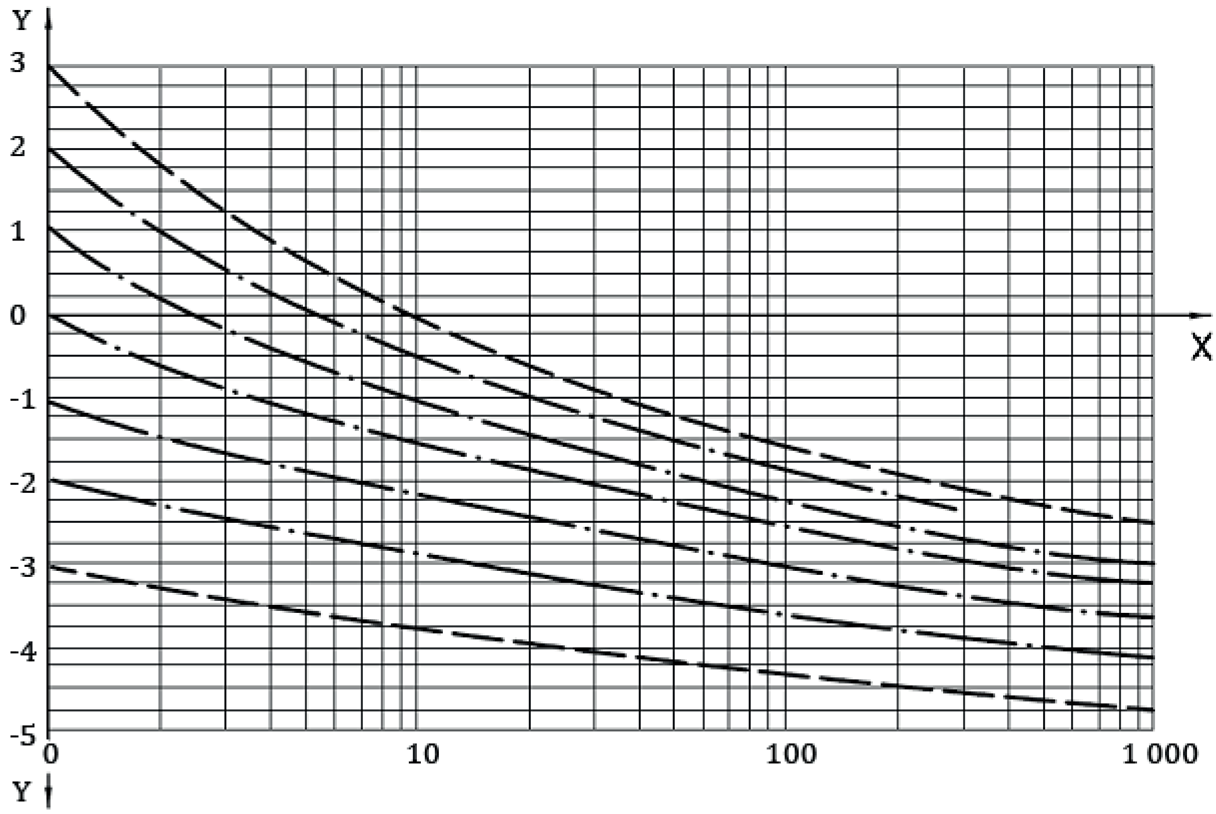
$Z_{(A,-3\sigma)}$ is the standard normal transform corresponding to A^N and $F_{b(-3SN)}$.

The standard deviation of the population (S_P) is estimated by simultaneously solving the Formulae (F.3) and (F.4). 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 F_{b1}, S_P, $Z_{(A,Fb)}$,and $Z_{(A,-3\sigma)}$.

Table F.1 — Adjusted probabilities (A^N) for specimen size (N)

N	−3σ		−2σ		−1σ		F_b		+1σ		+2σ		+3σ	
	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z	A^N	Z
1	0,998 650	−3,000	0,977 250	−2,000	0,841 345	−1,000	0,500 000	0,000	0,158 655	1,000	0,022 750	2,000	0,001 350	3,000
2	0,999 325	−3,205	0,988 560	−2,275	0,917 248	−1,387	0,707 107	−0,545	0,398 316	0,258	0,150 831	1,033	0,036 742	1,790
4	0,999 662	−3,399	0,994 263	−2,528	0,957 731	−1,725	0,840 896	−0,998	0,631 122	−0,335	0,388 370	0,284	0,191 682	0,872
8	0,999 831	−3,584	0,997 128	−2,762	0,978 637	−2,026	0,917 004	−1,385	0,794 432	−0,822	0,623 193	−0,314	0,437 815	0,157
12	0,999 887	−3,689	0,998 084	−2,892	0,985 707	−2,189	0,943 874	−1,588	0,857 771	−1,070	0,729 595	−0,612	0,576 581	−0,193
16	0,999 916	−3,761	0,998 563	−2,981	0,989 261	−2,299	0,957 603	−1,724	0,891 309	−1,234	0,789 426	−0,804	0,661 676	−0,417
20	0,999 932	−3,816	0,998 850	−3,048	0,991 400	−2,382	0,965 936	−1,824	0,912 059	−1,354	0,827 655	−0,945	0,718 648	−0,579
24	0,999 944	−3,863	0,999 042	−3,103	0,992 828	−2,449	0,971 532	−1,904	0,926 159	−1,448	0,854 163	−1,054	0,759 329	−0,704
28	0,999 952	−3,900	0,999 178	−3,148	0,993 849	−2,503	0,975 549	−1,969	0,936 364	−1,525	0,873 616	−1,144	0,789 790	−0,806
32	0,999 958	−3,930	0,999 281	−3,187	0,994 616	−2,550	0,978 572	−2,025	0,944 092	−1,590	0,888 496	−1,219	0,813 435	−0,891
36	0,999 962	−3,958	0,999 361	−3,221	0,995 213	−2,591	0,980 930	−2,073	0,950 146	−1,646	0,900 245	−1,283	0,832 313	−0,963
40	0,999 966	−3,986	0,999 425	−3,251	0,995 690	−2,627	0,982 821	−2,116	0,955 018	−1,696	0,909 755	−1,339	0,847 731	−1,027
60	0,999 977	−4,079	0,999 617	−3,364	0,997 125	−2,762	0,988 514	−2,274	0,969 782	−1,878	0,938 894	−1,546	0,895 720	−1,258
80	0,999 983	−4,144	0,999 712	−3,443	0,997 843	−2,854	0,991 373	−2,381	0,977 250	−2,000	0,953 811	−1,683	0,920 723	−1,410
100	0,999 986	−4,200	0,999 770	−3,503	0,998 274	−2,924	0,993 092	−2,462	0,981 758	−2,091	0,962 875	−1,785	0,936 059	−1,523
120	0,999 989	−4,238	0,999 808	−3,551	0,998 561	−2,981	0,994 240	−2,527	0,984 775	−2,164	0,968 965	−1,866	0,946 425	−1,611
140	0,999 990	−4,275	0,999 836	−3,591	0,998 767	−3,027	0,995 061	−2,580	0,986 936	−2,224	0,973 339	−1,932	0,953 899	−1,684
160	0,999 992	−4,303	0,999 856	−3,626	0,998 921	−3,068	0,995 677	−2,626	0,988 560	−2,275	0,976 632	−1,989	0,959 543	−1,745
200	0,999 993	−4,359	0,999 885	−3,683	0,999 137	−3,134	0,996 540	−-2,701	0,990 837	−2,359	0,981 262	−2,081	0,967 501	−1,845
240	0,999 994	−4,396	0,999 904	−3,730	0,999 280	−3,187	0,997 116	−2,761	0,992 358	−2,426	0,984 360	−2,154	0,972 844	−1,924
300	0,999 995	−4,433	0,999 923	−3,786	0,999 424	−3,251	0,997 692	−2,833	0,993 882	−2,505	0,987 469	−2,240	0,978 215	−2,018
360	0,999 996	−4,470	0,999 936	−3,830	0,999 520	−3,302	0,998 076	−2,890	0,994 899	−2,569	0,989 546	−2,310	0,981 813	−2,093
400	0,999 997	−4,508	0,999 942	−3,856	0,999 568	−3,332	0,998 269	−2,923	0,995 408	−2,605	0,990 587	−2,349	0,983 617	−2,135
500	0,999 997	−4,545	0,999 954	−3,912	0,999 655	−3,393	0,998 615	−2,992	0,996 325	−2,681	0,992 462	−2,431	0,986 872	−2,222
600	0,999 998	−4,582	0,999 962	−3,953	0,999 712	−3,443	0,998 845	−3,047	0,996 936	−2,741	0,993 715	−2,496	0,989 048	−2,292



Key

X specimen size, *N*

Y adjusted probability, standard normal transform units, *Z*

Figure F.1 — Adjusted probabilities (A^N) for specimen size (*N*)

F.2.2 Sample size

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

F.2.3 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 30 specimens, equally representing at least three different production batches.

F.3 Other factors

F.3.1 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 is small, but does exist. Either user should be warned of this possibility of fatigue failure, or the chain producer should make additional compensation for it.

F.3.2 Fatigue life

Limited testing shows there are some link plate fatigue failures beyond 10^7 cycles, which indicates that 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 clear directive can be given on this, but both users and producers should be aware of this possibility of fatigue failure.

F.3.3 Wear

Testing indicates that chain and sprocket/sheave wear can reduce the fatigue strength and life of transmission chain and leaf chain. Great variation virtually precludes the prediction of wear effects, but here again, both users and producers should be aware of the possibility of fatigue failure.

F.3.4 Unidentified factors

Many other factors, not listed here, may affect the fatigue life of transmission chain and leaf chain. One common way to treat them is by clearly enumerating the drive conditions under which the ratings apply and exclude everything else.

F.4 Sample calculations

In this example, each of the three production batches had low variation (3-step staircases), but the means differed by about two steps. The constructed 30-test staircase appears as follows:

Test force N	Staircase																													
19 450					x		x																							
17 600		x		o		o		X		x		x						x												
15 750	o		o						o		o		x		x		o		x		x		x				x			
13 900														o		o				o		o		x		o		x		o
12 050																									o				o	

Basic statistics for this staircase are

— mean fatigue strength, F_b = 15 688;

— standard deviation, S = 1 880;

— minimum fatigue strength, $F_b - 3S$ = 10 048;

— fatigue limit: $F_b - 3S + d$ = 11 898.

In this example, test chain length was 13 pitches, with inner link each end (N = 28). Adjustments for chain length are as follows:

$15\ 688 = F_{b1} - 1{,}969\ S_P$ a) $F_{b1} = 15\ 688 + 1{,}969\ (1\ 963)$

$11\ 898 = F_{b1} - 3{,}900\ S_P$ b) $F_{b1} = 19\ 553$

Subtracting b) from a) results in

$3\ 790 = 1{,}931\ S_P$

$S_P = 1\ 963$

So, for a transmission chain 100 pitches long:

— mean fatigue strength, $F_{b200} = 19\ 553 - 2{,}701\ (1\ 963) = 19\ 553 - 5\ 302 = 14\ 251$;

— minimum fatigue limit, $F_{b(-3S200)}$ = 19 553 – 4,359 (1 963) = 19 553 – 8 557 = 10 996.

And, for a transmission chain 120 pitches long:

— mean fatigue strength, F_{b240} = 19 553 – 2,761 (1 963) = 19 553 – 5 420 = 14 133;

— minimum fatigue limit, $F_{b(-3S240)}$ = 19 553 – 4,396 (1 963) = 19 553 – 8 629 = 10 924.

Annex G
(informative)

Extrapolating fatigue strength from 3×10^6 to 10^7 cycles

G.1 General

Endurance for the conformity test is 3×10^6 cycles, while endurance for the fatigue limit is 10^7 cycles. It follows then that a method is needed to extrapolate from a conformity test value at 3×10^6 cycles to a corresponding fatigue limit at 10^7 cycles. This Annex gives one method of doing that. This procedure can be used in transmission chains and leaf chains.

G.2 Test data

Several staircase fatigue test series for 80 chain were selected, for nearly identical means and variances. Endurance for all test series was 10^7 cycles. All test chains were 13 free pitches long with an inner link at each end.

The fatigue tests were run on a Schenck, 10-tonne, mechanical harmonic-spring, axial tensile fatigue testing unit. Minimum force was 2 225 N throughout all test series. Test forces, corrected to zero minimum force, were 13 900 N, 15 750 N, 17 600 N, 19 450 and 21 300 N. Step size was 1 850 N.

G.3 Constructed staircases

G.3.1 Phantom points

All of the test data were from tests run to 10^7 cycles. Staircases, with endurance set at 5×10^6 cycles and 3×10^6 cycles, were synthesized from that original data. When endurance was set at 5×10^6 cycles and 3×10^6 cycles, some of the failures in the tests run to 10^7 cycles became run-outs at the lesser endurance.

There were not enough test points at higher force levels to complete a synthesized staircase, so phantom points were added. All phantom test points were assumed to be failures to make the analysis conservative.

Some data points at lower force levels had to be discarded because there were not sufficient data points at the next higher level to justify their inclusion in the synthesized staircase.

G.3.2 Constructed staircase with endurance at 10^7 cycles

A staircase was constructed from the selected test data with endurance at 10^7 cycles. This constructed staircase contained seventy-six data points on four force levels.

G.3.3 Constructed staircase with endurance at 5×10^6 cycles

Next, endurance was set at 5×10^6 cycles for the staircase data in G.3.2. Two of the failures at the 19 450 N force level became run-outs, six of the failures at the 17 600 N force level became run-outs, and two of the failures at the 15 750 N force level became run-outs. Following the guidelines in G.3.1, two phantom points were added at the 21 300 N force level and eight phantom points were added at the 19 450 N force level. Eight tests were discarded at the 15 750 N force level and two tests were discarded at the 13 900 N force level.

G.3.4 Constructed staircase with endurance at 3 × 10^6 cycles

Finally, endurance was set at 3 × 10^6 cycles for the staircase data in G.3.2. Three of the failures at the 19 450 N force level became run-outs, eight of the failures at the 17 600 N force level became run-outs, and two of the failures at the 15 750 N force level became run-outs. Following the guidelines in G.3.1, three phantom points were added at the 21 300 N force level and ten phantom points were added at the 19 450 N force level. Ten tests were discarded at the 15 750 N force level and two tests were discarded at the 13 900 N force level.

G.3.5 Sample staircases and histograms

Sample staircases are shown in Figure G.1. Sample histograms are shown in Figure G.2.

G.4 Staircase analysis

G.4.1 Means

Only the mean fatigue strength was calculated for each constructed staircase. Standard deviations were not calculated because the addition of the phantom points could make them unreliable.

The calculated mean fatigue strengths were 16 724 N for endurance at 10^7 cycles, 17 308 N for endurance at 5 × 10^6cycles, and 17 456 N for endurance at 3 × 10^6 cycles.

G.4.2 Differences

Mean fatigue strength was 3,5 % higher with endurance at 5 × 10^6 cycles, and 4,4 % higher with endurance at 3 × 10^6 cycles. The slope of the Log *F* - Log *N* line could have been determined by taking the slope from 3 × 10^6 to 10^7 cycles, the slope from 5 × 10^6 to 10^7 cycles, or an average of the two. It was decided to use the slope from 3 × 10^6 to 10^7 cycles because the dynamic strength requirements in ISO 606, ISO 10190 and ISO 4347 were set at 3 × 10^6 cycles, and that slope appeared to best fit the failure data.

G.4.3 Fatigue test staircases for 80 chain

Force N	Staircase																																																												
19 450						x						x						x						x						x		x		x		x		x																								
17 600					o		x				o		x				o		x				o		x				o		o		o		o		o		x						x		x		x		x		x		x		x		x		x	
15 750		x		o				x		o				x		o				x		o				x		o												x		x		o		o		o		o		o		o		o		o		o		o
13 900	o		o						o						o						o						o														o		o																			

a) Endurance = 3 × 10^7 cycles AVG FS = 16 724

Force N	Staircase																																																												
21 300							#								#																																															
19 450						o		x						o		x						x						x						x				x				x				#				#				#				#				#
17 600					o				x				o				x				o		x				o		x				o		x		o		x		o		x		o		x		o		x		o		x		o		x		o	
15 750		x		o						x		o						x		o				x		o				x		o				o				o				o				o				o				o				o		
13 900	o		o								o								o						o						o																															

b) Endurance = 5 × 10^6 cycles AVG FS = 17 308 +3,5 %

Force N	Staircase																																																												
21 300							#								#								#																																							
19 450						o		x						o		x						o		x						x						x				x				#				#				#				#				#		
17 600					o				x				o				x				o				x				o		x				o		x		o		x		o		x		o		x		o		x		o		x		o		x	
15 750		x		o						x		o						x		o						x		o				x		o				o				o				o				o				o				o		o
13 900	o		o								o								o								o						o																													

c) Endurance = 3 × 10^6 cycles AVG FS = 17 456 +4,4 %

Key

x failure

o run-out

assumed failure

Figure G.1 — Sample staircases

G.4.4 Fatigue test histograms for 80 chain

Force N	Histogram																													
19 450	X	X	X	X	X	X	X	X	X																					
17 600	O	O	O	O	O	O	O	O	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15 750	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X	X	X	X	
13 900	O	O	O	O	O	O	O	O																						
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

a) Endurance = 10^7 cycles AVG FS = 16 724

Force N	Histogram																													
21 300	#	#																												
19 450	O	O	X	X	X	X	X	X	X	#	#	#	#	#	#	#	#													
17 600	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X	X	X	X	X	X	X	X	X	X	X	X
15 750	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X	X									
13 900	O	O	O	O	O	O																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

b) Endurance = 5×10^6 cycles AVG FS = 17 308 +3,5 %

Force N	Histogram																													
21 300	#	#	#																											
19 450	O	O	O	X	X	X	X	X	X	#	#	#	#	#	#	#	#	#	#											
17 600	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X	X	X	X	X	X	X	X	X	X
15 750	O	O	O	O	O	O	O	O	O	O	O	O	O	O	X	X	X	X	X											
13 900	O	O	O	O	O	O																								
	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24	25	26	27	28	29	30

c) Endurance = 3×10^6 cycles AVG FS = 17 456 +4,4 %

Key

x failure

o run-out

assumed failure

Figure G.2 — Sample histograms

Annex H
(informative)

Finite life testing and data analysis

H.1 General

Finite life testing and analysis is used to determine the relationship between force and cycles to failure at numbers of cycles less than the inflection point.

H.2 Test procedure

H.2.1 Test specimens

At least 14 test specimens shall be prepared in accordance with Clause 6. All test specimens shall be from the same production batch.

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

H.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 and leaf chain.

H.2.3 Force levels

H.2.3.1 Number of force levels

There shall be at least two, but not more than four, force levels in a finite life test.

H.2.3.2 Values of force levels

The maximum test force shall not be more than 60 % of the minimum tensile strength listed in ISO 606, ISO 10190 or ISO 4347.

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 neighbouring force levels should be as nearly equal as possible.

H.2.4 Number of tests

A minimum of 14 specimens shall be tested. As near an equal number of tests as possible 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, five and four specimens at each of three force levels, and

— four, four, three and three specimens at each of four force levels.

H.3 Data analysis

H.3.1 Data

The data for a finite life analysis shall be gathered in accordance with H.2

H.3.2 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.

H.3.3 Determining force–life (*F*–*N*) lines

H.3.3.1 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.

H.3.3.2 Mean regression line: 0,50 probability of survival

H.3.3.2.1 Normal force distribution

If a normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Formulae (H.1), (H.2), and (H.3).

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

$$N = \exp_{10}\left[\lg N_0 + m_F F_a\right] \tag{H.1}$$

The slope of the line is

$$m_F = \frac{n_f \Sigma F_{d_i} \lg N_i - \Sigma F_{d_i} \Sigma \lg N_i}{n_f \Sigma \left(F_{d_i}\right)^2 - \left(\Sigma F_{d_i}\right)^2} \tag{H.2}$$

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

$$N_0 = \exp_{10}\left[\frac{\Sigma \lg N_i - m_F \Sigma F_{d_i}}{n_f}\right] \tag{H.3}$$

H.3.3.2.2 Log-normal force distribution

If a log-normal distribution of force is chosen for analysis, the mean regression line shall be estimated by means of Formulae (H.4), (H.5), and (H.6).

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

$$N = \exp_{10}\left[\lg N_0 + m_{LF} \lg F_a\right] \tag{H.4}$$

The slope of the line is

$$m_{LF} = \frac{n_f \Sigma\left(\lg F_{d_i} \lg N_i\right) - \Sigma \lg F_{d_i} \Sigma \lg N_i}{n_f \Sigma\left(\lg F_{d_i}\right)^2 - \left(\Sigma \lg F_{d_i}\right)^2} \tag{H.5}$$

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

$$N_1 = \exp_{10}\left[\frac{\Sigma \lg N_i - m_{LF} \Sigma \lg F_{d_i}}{n_f}\right] \tag{H.6}$$

H.3.3.3 Minimum regression line: 0,97725 (−2σ) probability of survival

H.3.3.3.1 Normal force distribution

If a normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Formulae (H.7) and (H.8).

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

$$S_{\lg N} = \left[\frac{\Sigma \lg N_i^{\,2} - \lg N_0 \Sigma \lg N_i - m_F \Sigma\left(\lg N_i F_{d_i}\right)}{n_f - 2}\right]^{0,5} \tag{H.7}$$

and the relationship between minimum fatigue life N_{min} and applied force F_a, between 10^4 and 10^6 cycles, with a 0,977 25 probability of survival, is

$$N_{min} = \exp_{10}\left(\lg N_0 - 2S_{\lg N} + m_F F_a\right) \tag{H.8}$$

H.3.3.3.2 Log-normal force distribution

If a log normal distribution of force is chosen for analysis, the minimum regression line shall be estimated by means of Formulae (H.9) and (H.10).

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

$$S_{\lg N} = \left[\frac{\Sigma \lg N_i^{\,2} - \lg N_1 \Sigma \lg N_i - m_{LF} \Sigma\left(\lg N_i \lg F_{d_i}\right)}{n_f - 2}\right]^{0,5} \tag{H.9}$$

and the relationship between minimum fatigue life N_{Lmin} and applied force F_a between 10^4 and 10^6 cycles, with a 0,977 25 probability of survival, is

$$N_{Lmin} = \exp_{10}\left[\lg N_1 - 2S_{\lg N} + m_{LF} \lg F_a\right] \tag{H.10}$$

H.4 Sample test results

A finite life test was conducted on “BCD Chain” Company’s number 80 chain, consisting of 14 tests run on three force levels. The results are shown on the sample test result form which follows and, graphically, in Figures H.1 and H.2

Fatigue test report

Report no.: 1002 Page 1 of 1 Report date: 2011-06-10

Chain:

Brand	Number	Pitch	Specimen length	Other	Minimum dynamic Specification
BCD chain	80	25,4 mm	5P, ILEE		

Mechanical properties

Not taken

Test:

Type	Endurance	Temperature	Other
Finite life		Approx. 15 °C	Low humidity

Machine:

Brand	Type	No. used	Calibration date	Force verification and monitoring
XYZ	Mech., harmonic spring	1	2011-05-20	Periodic, strain-gauge bar

Date	**Test no.**	**Frequency** Hz	F_{max} kN	F_{min} kN	F_d kN	**Cycles** N	**Failure**	**Remarks**
11-06-05	001	33	33,36	2,224	32,43	4,500E4	IP	
11-06-05	002	33	33,36	2,224	32,43	6,750E4	IP	
11-06-05	003	33	33,36	2,224	32,43	3,375E4	IP	
11-06-06	004	33	33,36	2,224	32,43	2,925E4	IP	
11-06-06	005	33	33,36	2,224	32,43	5,980E4	IP	
11-06-06	006	33	27,80	2,224	26,64	1,596E5	IP	
11-06-07	007	33	27,80	2,224	26,64	9,000E4	IP	
11-06-07	008	33	27,80	2,224	26,64	7,800E4	IP	
11-06-08	009	33	27,80	2,224	26,64	1,800E5	IP	
11-06-08	010	33	27,80	2,224	26,64	1,200E5	IP	
11-06-08	011	33	22,24	2,224	20,85	3,845E5	IP	
11-06-09	012	33	22,24	2,224	20,85	2,884E5	IP	
11-06-09	013	33	22,24	2,224	20,85	5,770E5	IP	
11-06-09	014	33	22,24	2,224	20,85	5,114E5	IP	

Results and conclusions:

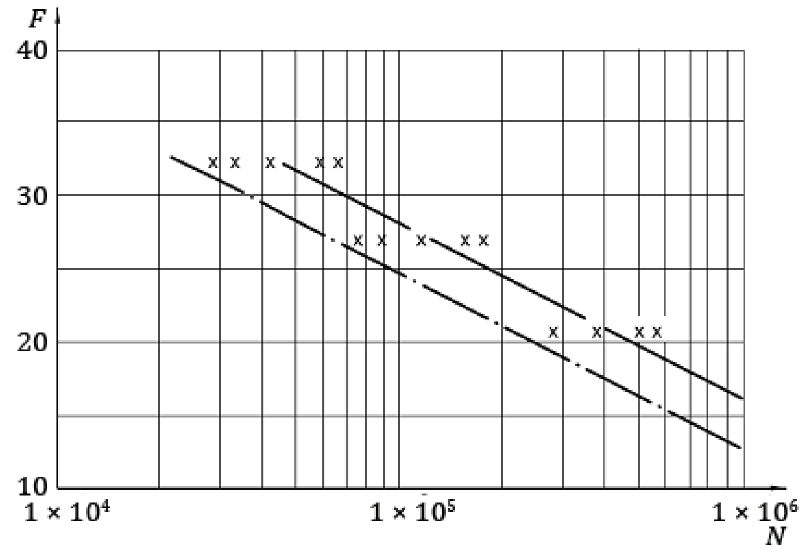
m_F = −0,083 995 m_{LF} = −5,096 649

$\lg N_0$ = 7,354 8 $\lg N_1$ = 12,348 38

$S_{\lg N0}$ = 0,147 42 $S_{\lg N1}$ = 0,143 87

The results of the finite-life tests are plotted on the attached graphs [see Figures H.1 and H.2].

Signed: *John Smith*

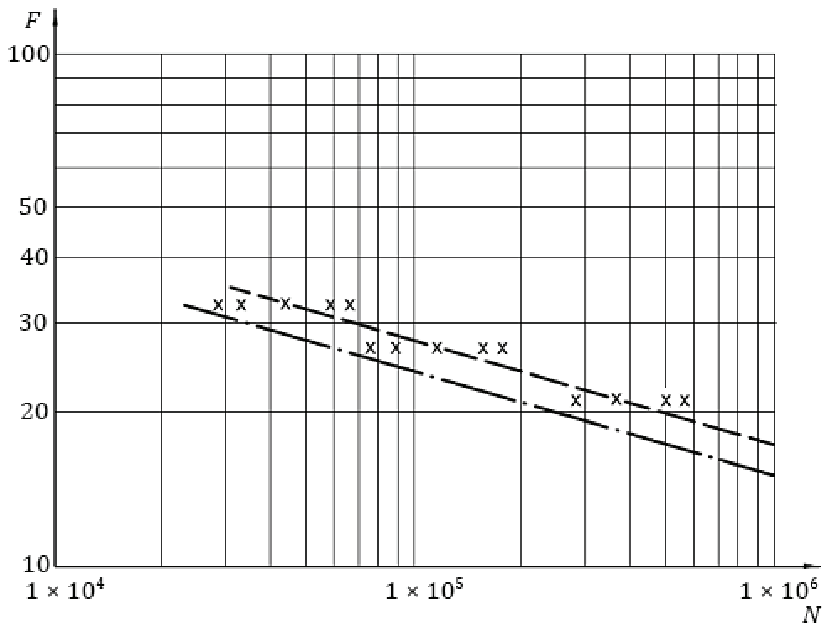


Key

F force, kN

N life, cycles

Figure H.1 — Typical *F*–Log *N* graph for 80 chain



Key

F force, kN

N life, cycles

Figure H.2 — Typical Log *F*–Log *N* graph for 80 chain

Bibliography

[1] ISO 10823, *Guidelines for the selection of roller chain drives*

[2] ISO 1099, *Metallic materials — Fatigue testing — Axial force-controlled method*

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