BS ISO 12110-2:2013

BSI Standards Publication

Metallic materials — Fatigue testing — Variable amplitude fatigue testing

Part 2: Cycle counting and related data reduction methods

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National foreword

This British Standard is the UK implementation of ISO 12110-2:2013.

The UK participation in its preparation was entrusted to Technical Committee ISE/101/6, Fatigue testing of metals and metal matrix composites.

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

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Metallic materials — Fatigue testing — Variable amplitude fatigue testing —

Part 2:
Cycle counting and related data reduction methods

Matériaux métalliques — Essais de fatigue — Essais sous amplitude variable —

Partie 2: Méthodes de comptage des cycles et méthodes associées de réduction des données

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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.

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The committee responsible for this document is ISO/TC 164, *Mechanical testing of metals*, Subcommittee SC 5, *Fatigue testing*.

ISO 12110 consists of the following parts, under the general title *Metallic materials — Fatigue testing — Variable amplitude fatigue testing*:

— *Part 1: General principles, test method and reporting requirements*

— *Part 2: Cycle counting and related data reduction methods*

Metallic materials — Fatigue testing — Variable amplitude fatigue testing —

Part 2:
Cycle counting and related data reduction methods

1 Scope

This part of ISO 12110 presents cycle counting techniques and data reduction methods which are used in variable amplitude fatigue testing.

For each test or test series, cycle counting is mandatory whereas data reduction methods are optional.

This part of ISO 12110 supports ISO 12110-1 which contains the general principles and describes the common requirements about variable amplitude fatigue testing.

In this part of ISO 12110, the term “loading” refers either to force, stress, or strain since the methods presented here are valid for all.

The following issues are not within the scope of this part of ISO 12110 and therefore will not be addressed:

— constant amplitude tests with isolated overloads or underloads;

— large components or structures;

— environmental effects like corrosion, creep, etc. linked to temperature/time interactions leading to frequency and waveform effects;

— multiaxial loading.

NOTE 1 Phasing is of prime importance when dealing with multiaxial tests under either constant or variable amplitude controlled loading.

NOTE 2 Although frequency variations during cycling are not outside of the scope of this part of ISO 12110, the following clauses deal only with constant frequency cycling.

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 12110-1, *Metallic materials — Fatigue testing — Variable amplitude fatigue testing — Part 1: General principles, test method and reporting requirements*

3 Terms and definitions

For the purposes of this document, the terms and definitions given in ISO 12110-1 and the following apply.

3.1
mean crossing
number of times that the load-time history crosses the mean-load level with a positive slope or a negative slope, or both, if specified during a given length of the history

Note 1 to entry: For purposes related to cycle counting, a mean crossing may be defined as a crossing of the reference load level.

3.2
range
algebraic difference between two successive reversals

Note 1 to entry: In variable amplitude loading, range may have a different definition depending on the counting method used. For example, “overall range” is defined by the algebraic difference between the highest peak and the lowest valley (absolute maximum and minimum, respectively) of a given load-time history.

Note 2 to entry: In cycle counting by various methods, it is common to employ ranges between valley and peak loads which are not successive events. In these practices, the definition of “range” is broadened so that events of this type are also included.

3.3
reference load
loading level which is fixed for counting upon which load variations are superimposed

Note 1 to entry: The reference load may be identical to the mean load of the loading time histories, but this is not required.

3.4
reversal
point at which the first derivative of the load-time history changes sign (from + to – or – to +)

Note 1 to entry: Reversals occur at peaks or valleys.

3.5
irregularity factor
characterization of the irregularity of the signal, i.e. number of cycles not crossing the mean value, $I = N_0/N_p$

Note 1 to entry: N_0 is the number of mean crossings.

Note 2 to entry: N_p is the number of peaks.

3.6
mean-load level
mean value of the peak and valley values

4 Cycle counting techniques

4.1 General

Cycle counting is used to summarize irregular load-time histories by providing the number of cycles of various sizes which simulates the real loading of the specimen or component under study.

NOTE The definition of a cycle varies with the cycle counting method used.

Cycle counts can be made for load-time histories of force, stress, strain, deflection, or other loading parameters.

The following subclauses present the following cycle counting methods:

— level-crossing counting;

— peak counting;

— simple range counting;

— range-pair counting;

— Rainflow counting.

4.2 Cycle counting methods

4.2.1 Loading signal sampling

Loading signal recording generally consists of measuring the continuous evolution of the signal versus time (either analog or digital values against time). If the initial loading time history is analog, it needs to be converted into a digital file so that further computer processing of the loading time histories can be accomplished. The operation of digitization consists of sampling the signal that means measuring and recording values at regular time intervals.

The digital signal is representative of the real analog one if the following precautions are taken:

— Filter the output signal to eliminate noise and other disturbances which are not linked to the fatigue process believed to be part of the real loading time histories of the structure.

— The sampling frequency shall be such that every analog loading cycle is represented by at least 20 digital points at least 20 times that of the observed maximum frequency of the real or expected analog signal.

Care shall be taken when filtering the original analog signal. See ISO 12110-1.

4.2.2 Level-crossing counting

4.2.2.1 Results of a level-crossing count are shown in Figure 1. One count is recorded each time the positive sloped portion of the load exceeds a preset level above the reference load, and each time the negative sloped portion of the load exceeds a preset level below the reference load. Reference load crossings are typically counted on the positive sloped portion of the loading time histories. It makes no difference whether positive or negative slope crossings are counted. The distinction is made only to reduce the total number of events by a factor of 2.

4.2.2.2 In practice, restrictions on the level-crossing counts are often specified to eliminate small amplitude variations which can give rise to a large number of counts. This may be accomplished by filtering small load excursions prior to cycle counting. A second method is to make no counts at the reference load and to specify that only one count be made between successive crossings of a secondary lower level associated with each level above the reference load, or a secondary higher level associated with each level below the reference load. Figure 1 b) illustrates this second method. A variation of the second method is to use the same secondary level for all counting levels above the reference load, and another for all levels below the reference load. In this case, the levels are generally not evenly spaced.

4.2.2.3 The most common cycle count for fatigue analysis is derived from the level-crossing count by first constructing the largest possible cycle, followed by the second largest, etc., until all level crossings are used. Reversal points are assumed to occur halfway between levels.

This process is illustrated by Figure 1 c). Note that once this cycle count is obtained, the cycles could be applied in any desired order, and this order could have a secondary effect on the amount of damage. Other methods of deriving a cycle count from the level-crossing count could be used.

4.2.3 Peak counting

4.2.3.1 Peak counting identifies the occurrence of a relative maximum or minimum load value. Peaks above the reference load level are counted, and valleys below the reference load level are counted, as shown in Figure 2 a). Results for peaks and valleys are usually reported separately. A variation of this method is to count all peaks and valleys without regard to the reference load.

4.2.3.2 To eliminate small amplitude loadings, mean-crossing peak counting is often used. Instead of counting all peaks and valleys, only the largest peak or valley between two successive mean crossings is counted, as shown in Figure 2 b).

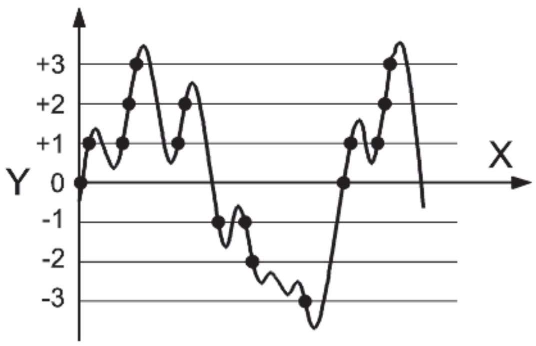
4.2.3.3 The most common cycle count for fatigue analysis is derived from the peak count by first constructing the largest possible cycle, using the highest peak and lowest valley, followed by the second largest cycle, etc., until all peak counts are used. This process is illustrated by Figure 2 c). Note that once this most damaging cycle count is obtained, the cycles could be applied in any desired order, and this order could have a secondary effect on the amount of damage. Alternate methods of deriving a cycle count, such as randomly selecting pairs of peaks and valleys, are sometimes used.

4.2.4 Simple-range counting

4.2.4.1 The method is illustrated in Figure 3. Positive ranges, negative ranges, or both, may be counted with this method. If only positive or only negative ranges are counted, then each is counted as one cycle. If both positive and negative ranges are counted, then each is counted as one-half cycle. Ranges smaller than preset levels are usually eliminated before counting.

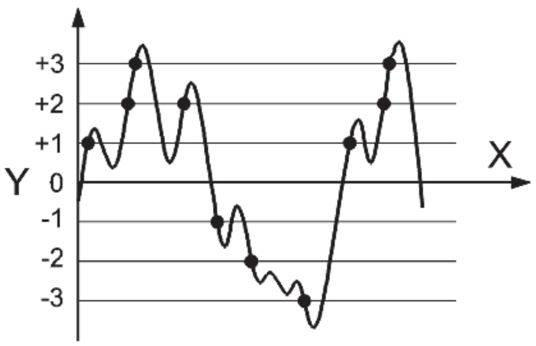
4.2.4.2 It is widely recognized that mean load also affects the measured fatigue results, which is why the mean value of each range is also important and should be counted. This method is called simple range-mean counting.

For the example in Figure 3, the result of a simple range-mean count is given in the table in Figure 3 in the form of a range and mean matrix.



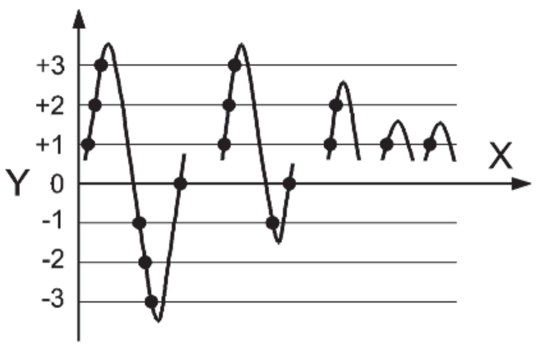
Level	Counts
+3	2
+2	3
+1	5
0	2
-1	2
-2	1
-3	1

a) Level-crossing counting



Level	Counts
+3	2
+2	3
+1	2
0	0
-1	1
-2	1
-3	1

b) Restricted level-crossing counting



Range (levels)	Cycle Counts
7	1
6	0
5	1
4	0
3	0
2	1
1	2

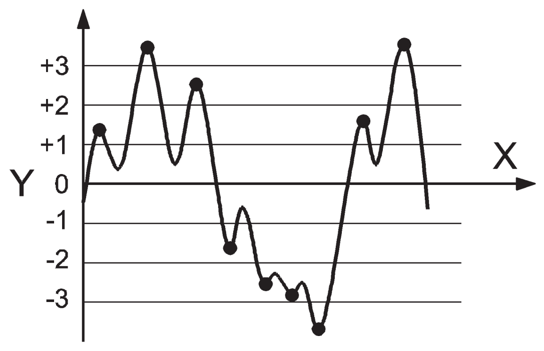
c) Cycles derived from level-crossing count *f (a)*

Key

X time

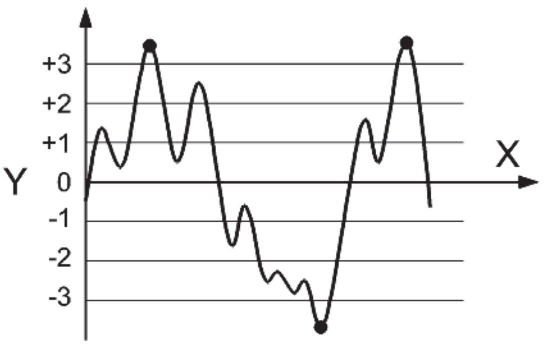
Y load levels

Figure 1 — Level-crossing counting example



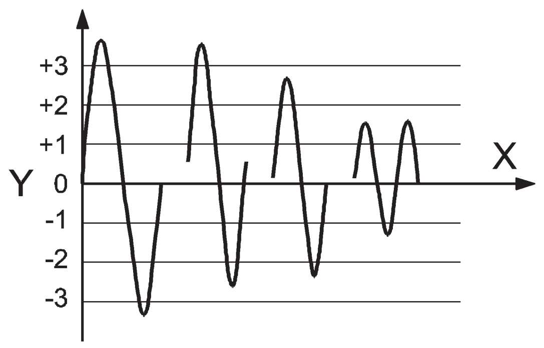
Level	Counts
+3,5	2
+2,5	1
+1,5	2
-1,5	1
-2,5	1
-2,7	1
-3,5	1

a) Peak counting



Level	Counts
+3,5	2
-3,5	1

b) Mean crossing peak counting



Level	Counts
7	1
6,2	1
5	1
3	1,5

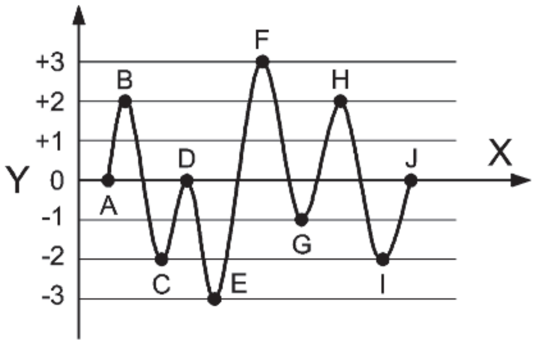
c) Cycles derived from level-crossing count *f (a)*

Key

X time

Y load levels

Figure 2 — Peak counting example



Range (level)	Cycle counts	Events
6	0,5	EF
5	0	
4	1,5	BC-FG-HI
3	1	DE-GH
2	1,5	AB-CD-IJ
1	0	

		Mean (levels)								
		-2	-1,5	-1	-0,5	0	0,5	1	1,5	2
Range (levels)	1									
	2			1				0.5		
	3		0,5				0,5			
	4					1		0,5		
	5									
	6						0,5			

Key

X time

Y load levels

Figure 3 — Simple range counting example — Both positive and negative ranges counted

4.2.5 Rainflow counting

See Annex A.

5 Counting technique selection

There are other cycle counting techniques which are not reported in this part of ISO 12110.

A major problem that has to be solved in each fatigue case (change of loading, of specimen, etc.) is to select which counting method is best adapted for the fatigue situation encountered.

A selection criterion may be narrow or large bandwidth energy spectrum and/or the irregularity factor.

Many choose the Rainflow method. Others use counting methods which are typical of their industrial sector.

In all cases, the selection of the counting method should follow a set of criteria or requirements.

Annex A
(informative)

Rainflow counting

A.1 General

The fatigue behaviour of structures depends on the complex interaction between the nature of the in-service loading, the features of the material, and the geometry of the components.

The Rainflow method is a cycle counting method that permits decomposing the measurements recorded in service using a format adapted to the fatigue analysis of the structures: fatigue life determination and performance of modelling tests.

The Rainflow analysis permits the determination of the level exceedances, their relative ranges, and cycle ranges.

The purpose of the present subclause is to give recommendations and requirements for

— performing the Rainflow cycle counting method, and

— presenting the results of the Rainflow counting.

An example of a loading sequence and the Rainflow analysis of it are presented as a test case to check how to use the Rainflow counting method and as a help for computer programming.

A.2 Preliminary treatment of the loading

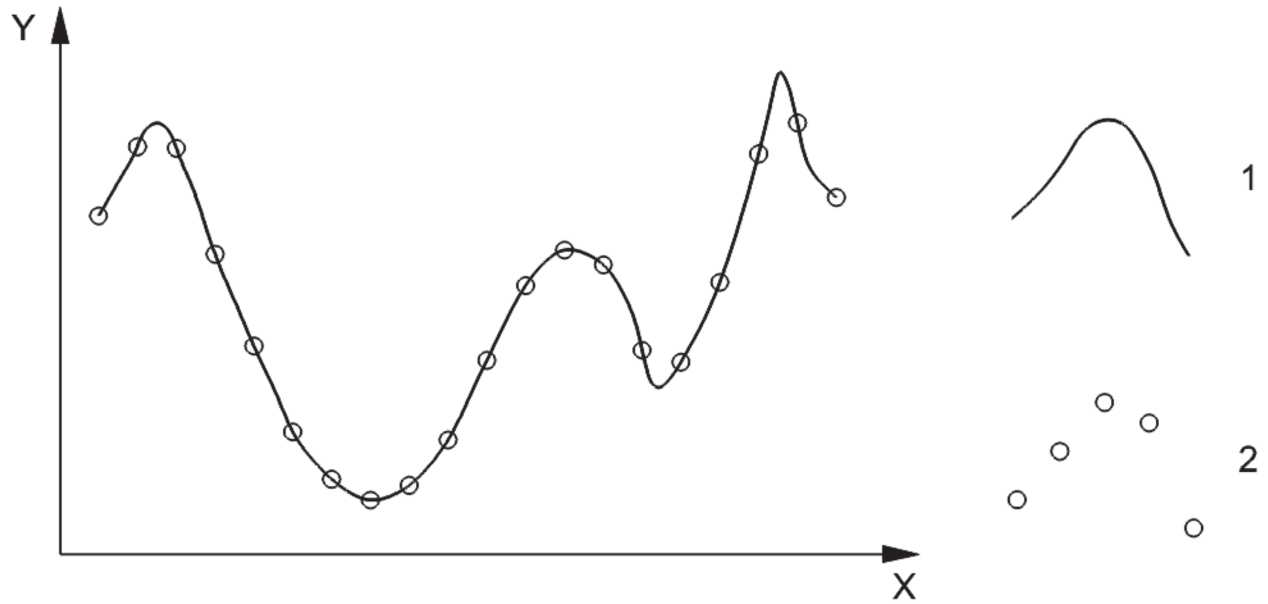
A.2.1 General

Before applying the Rainflow method, the loading signal requires a preliminary treatment which consists of extracting peaks and valleys and putting them in classes or levels which had been previously established (see 4.2).

A.2.2 Peak and valley extraction

The Rainflow counting only requires the successive peaks and valleys of the loading which need to be extracted for processing from the sampled signal. The time between the successive peaks and valleys is not part of the process because this part of ISO 12110 is only valid for conducting fatigue tests on materials that yield results which are time or frequency independent. Therefore, environmental and temperature or time interactions are not included in this part of ISO 12110. The fatigue life is expressed in number of cycles or in number of repetitions of the loading sequence.

Figures A.1 and A.2 show the principles of signal sampling and peak and valley extraction from the sampled signal.



Key

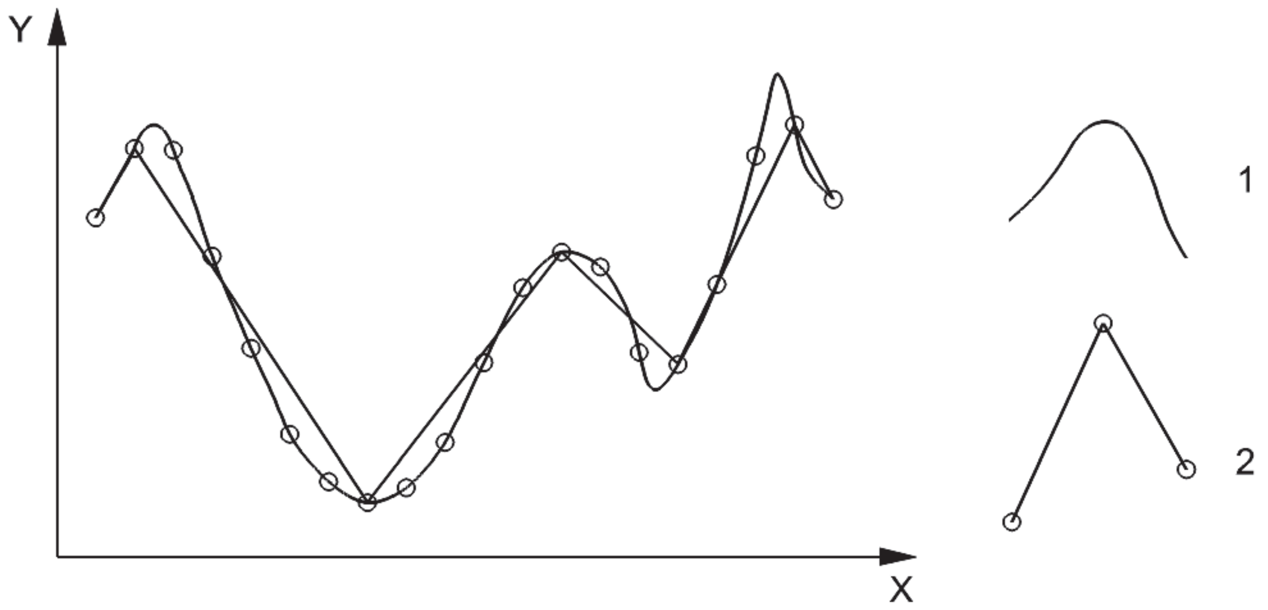
1 real loading

2 sampled loading

X time

Y stress range

Figure A.1 — Loading signal before extracting peaks and valleys



Key

1 real loading

2 peaks and valleys

X time

Y stress range

Figure A.2 — Loading signal after extracting peaks and valleys

A.2.3 Loading classes

The storage of the Rainflow counting results, on the one hand, and the speed of use of these results for further exploiting the fatigue signal, on the other hand, requires the quantification of the loading signal. Practically, the predicted or real loading range is partitioned into classes or levels of constant width intervals, and all values (peaks or valleys) located within a given class are conventionally equal to a representative value of this class. The representative value is mostly the arithmetic mean of the class.

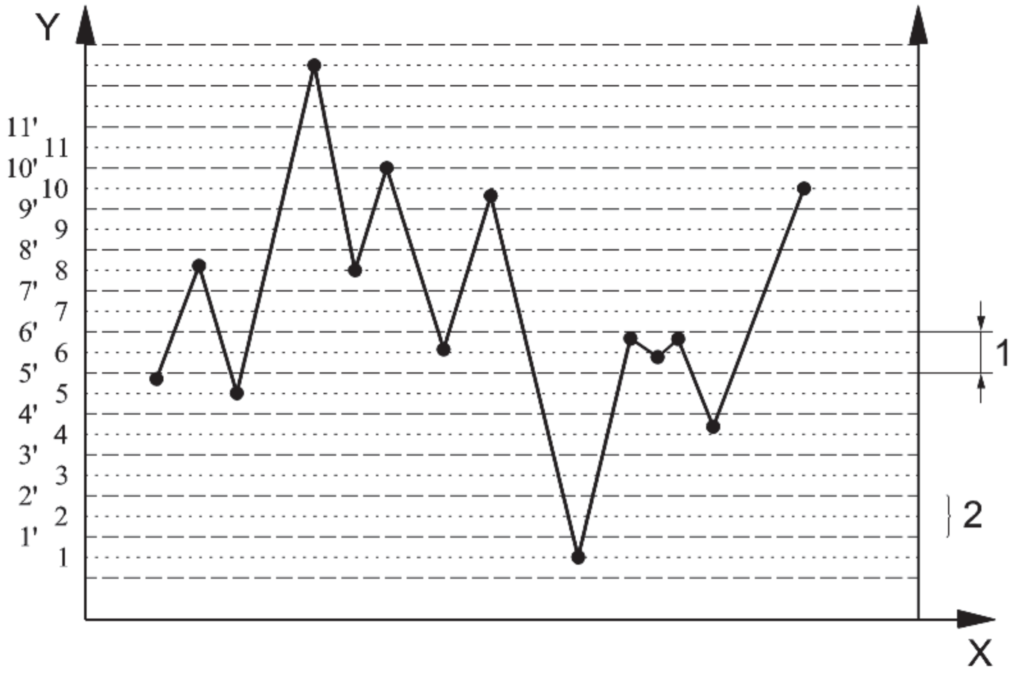
If a peak falls on a class limit, it is conventionally equal to the representative value of the neighbouring higher class; if a valley falls on a class limit, it is conventionally equal to the representative value of the neighbouring lower class.

Two sets of values are obtained through this process: the representative values and the values which correspond to class limits.

32 classes are recommended as a minimum (see ISO 12110-1).

NOTE General industrial practices adopt 64 load levels (see ISO 12110-1).

Loading signal treatment using class partitioning is shown in Figures A.3 and A.4.



Key

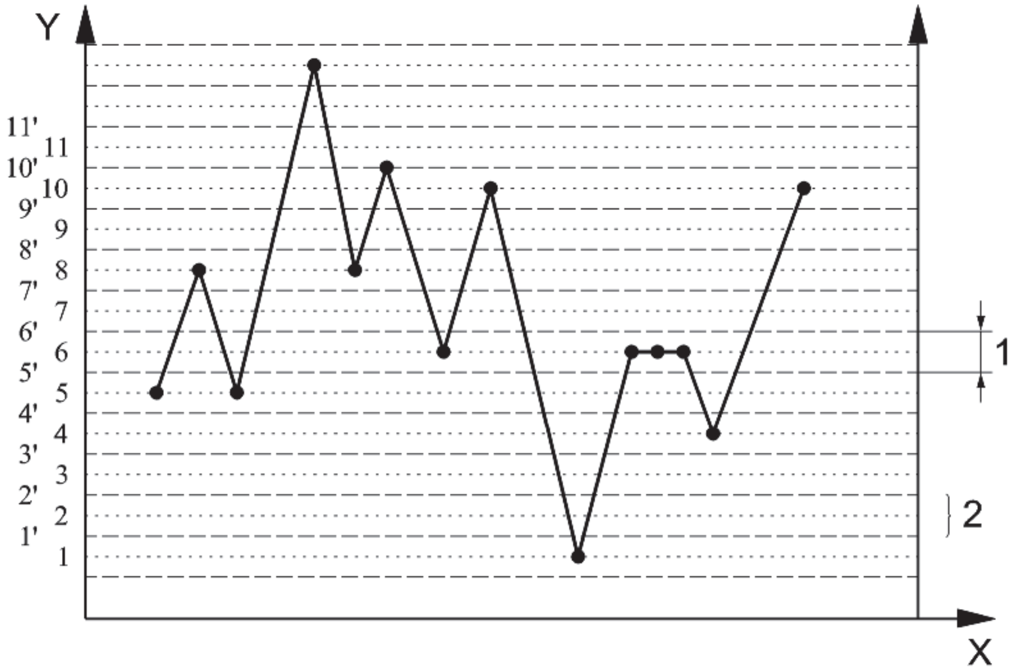
1 class width or class step

2 class 2

X time

Y stress range

Figure A.3 — Loading before treatment based on class partitioning



Key

1 class width or class step

2 class 2

X time

Y stress range

Figure A.4 — Loading after treatment

This treatment may lead to eliminate some successive values within the same class. If this happens too often, the present class partitioning is too loose and the number of classes has to be increased and the class width will be reduced (see ISO 12110-1).

A.3 Cycle counting procedure using the Rainflow method

A.3.1 Principle

The general principle of extraction of a loading cycle by the Rainflow method uses four successive points noted 1, 2, 3, and 4, respectively.

This can be illustrated in the following way: when S represents a stress level (as an example), the cycle is represented by, or considered as, a closed loop in the stress versus strain (S, e) plot.

Two cases of cycle occurrence have to be distinguished (Figure A.5).

The following three stress ranges are calculated: $\Delta S_1 = | S_2 - S_1 |$, $\Delta S_2 = | S_3 - S_2, |$, $\Delta S_3 = | S_4 - S_3 |$.

If $\Delta S_2 \leq \Delta S_1$ and $\Delta S_2 \leq \Delta S_3$ (the range ΔS_2 is lower or equal to the two other ranges), then

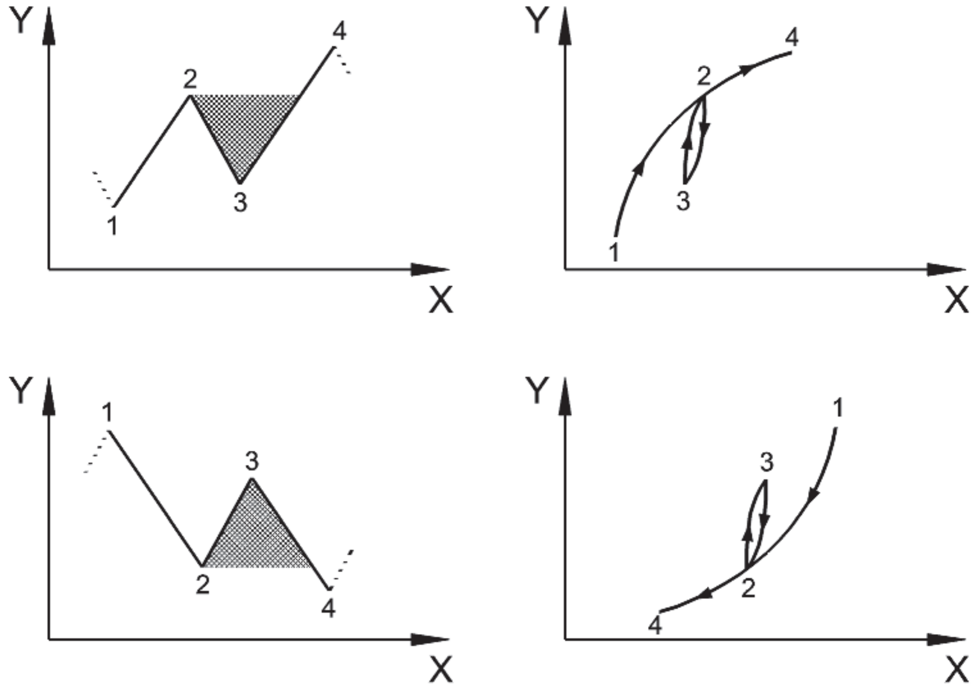
— the cycle represented by the extreme values S_2 and S_3 is extracted from the signal for further processing,

— the two S_2 points and S_3 are eliminated from the signal,

— the two parts of the signal situated on both sides of the extracted cycle extract are connected together.

Otherwise, the rank of appearance of the four points is shifted by one unit and the same procedure is applied again.

The procedure is repeated until the end of the signal.



Key

X time

Y stress range

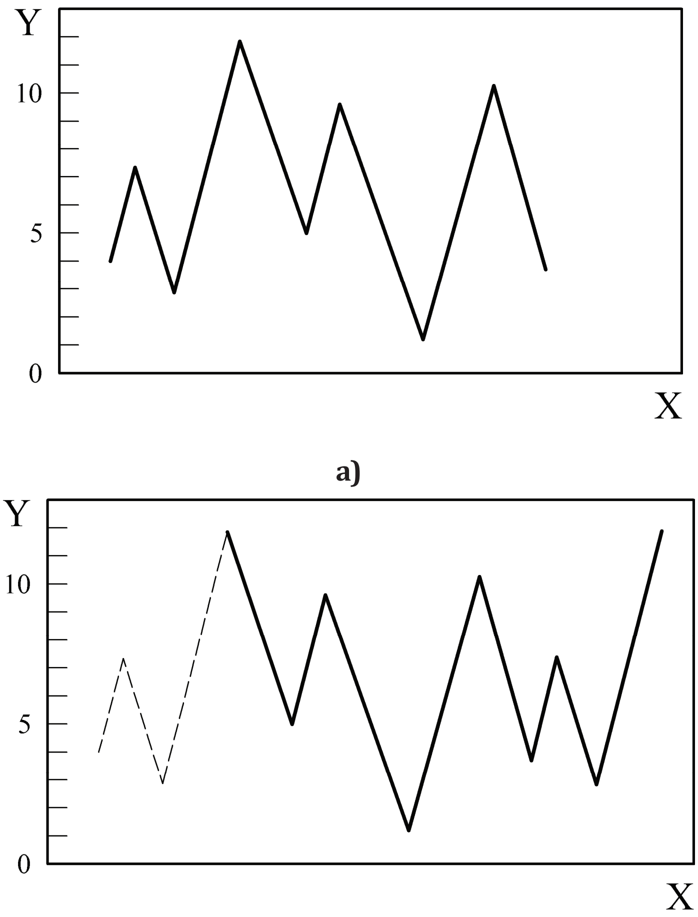
Figure A.5 — The two possible cases of cycle occurrence

When this operation is completed, some peaks and valleys have not been extracted because they do not belong to closed loops. So, the remaining points belong to the open cycle sequence which is defined as such.

The number of points of the open cycle sequence cannot exceed 2k-1, where k is the number of levels or classes.

The counts are reported in a matrix "starting class – destination class" or "minimal value S_{min} – S_{max}" or "S_m – ΔS" (see A.3.4.1), where S_{min}, S_{max}, and ΔS are minimum value, maximum value, and range, respectively.

If the global sequence is artificially closed by moving the part of the signal from the beginning to the absolute maximum at the end of the sequence (see Figure A.6), no open cycle sequence remains after the counting procedure.



b)

Figure A.6 — Procedure to artificially close a loading time history

A.3.2 Algorithm

The initial data are the successive values S_i $(1 \leq i \leq N)$ of the peaks and valleys of the loading which are the results of the preliminary treatment (see A.2).

The algorithm is presented in the flow chart of Figure A.6.

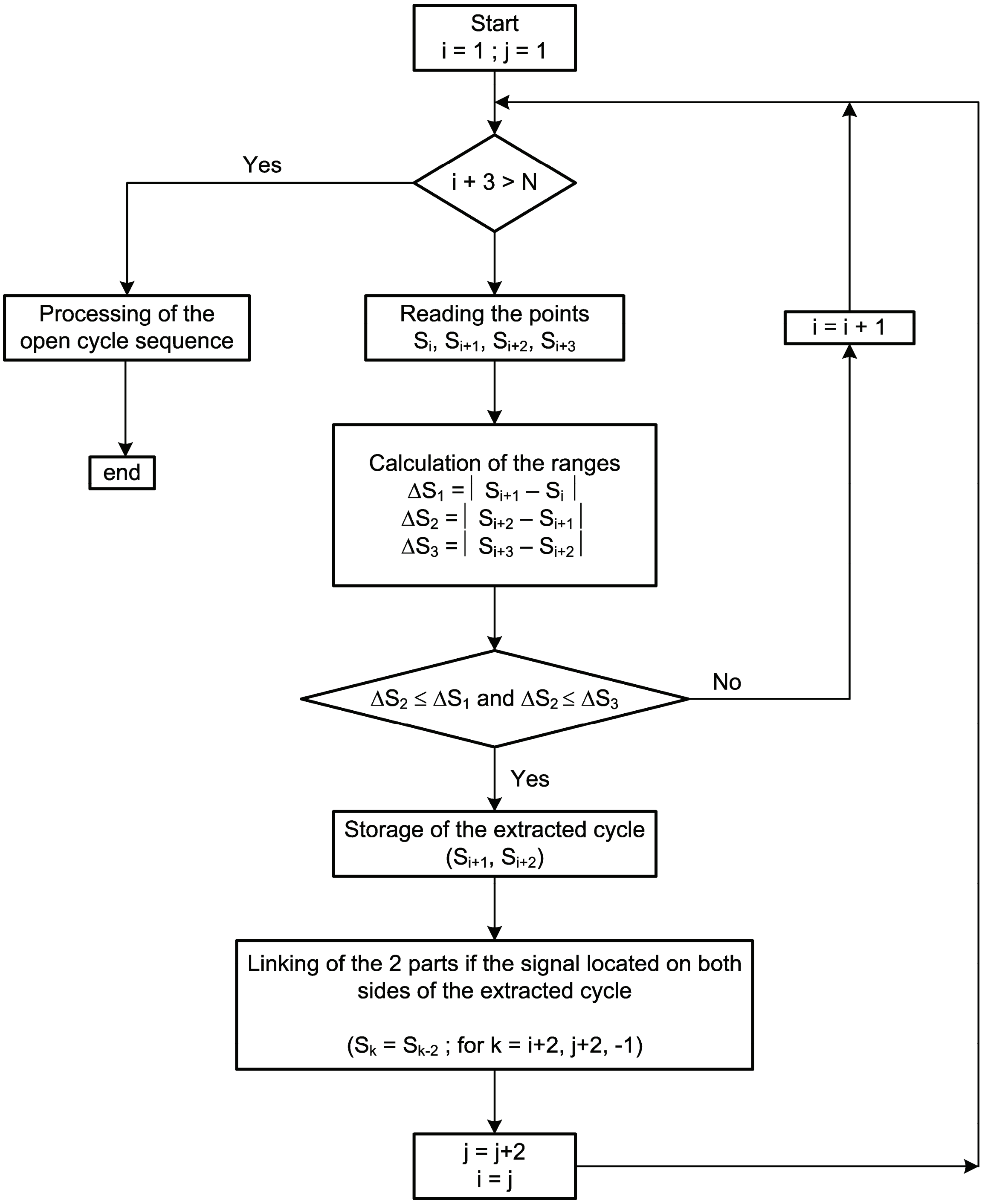


Figure A.7 — Algorithm of the Rainflow method

A.3.3 Use and treatment of the open cycle sequence

A.3.3.1 General

At the end of the counting, the open cycle sequence contains the non-closed cycles as defined in A.3.1 in the same order as the original signal. It can be either a signal where the successive ranges are increasing or decreasing (see Figure A.8). The greatest range consists of the highest maximum and the lowest minimum.

The open cycle sequence is then processed according to one of the two following methods:

— duplication of the open cycle sequence;

— closure of the open cycle sequence.

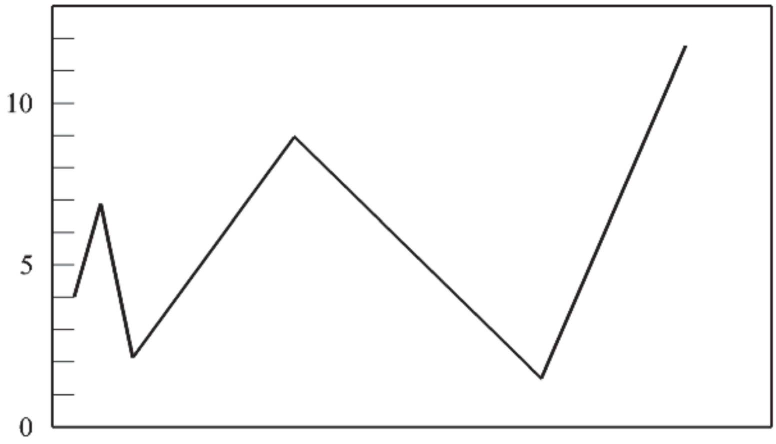


Figure A.8 — Open cycle sequence of the signal

A.3.3.2 Duplication of the open cycle sequence

The determination of the fatigue life requires that the loading signal can be regarded as a sequence of cycles. So, the open cycle sequence has to be treated to become a sequence of cycles.

The same open cycle sequence is added to that obtained from the counting process, but some precautions have to be taken regarding the link between the two identical sequences taking into account the values of the peaks or valleys to be linked as well as the first and last slopes of the open cycle sequence (see Figure A.9).

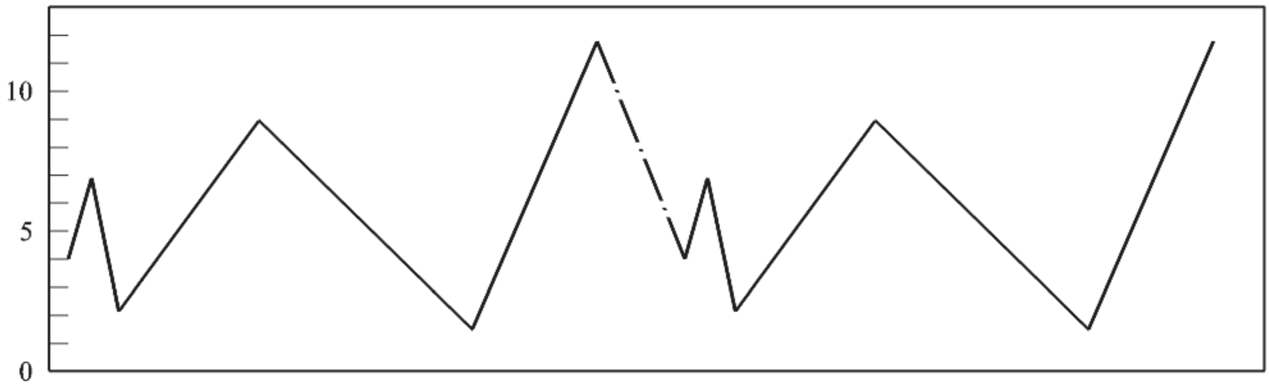


Figure A.9 — Signal used for the treatment of the open cycle sequence (duplication of the open cycle sequence)

When the Rainflow counting method is applied to the sequence formed by the two successive identical open cycle sequences, the initial open cycle sequence is obtained again (see Figure A.8). The extracted cycles correspond, therefore, to the cycles of the open cycle sequence.

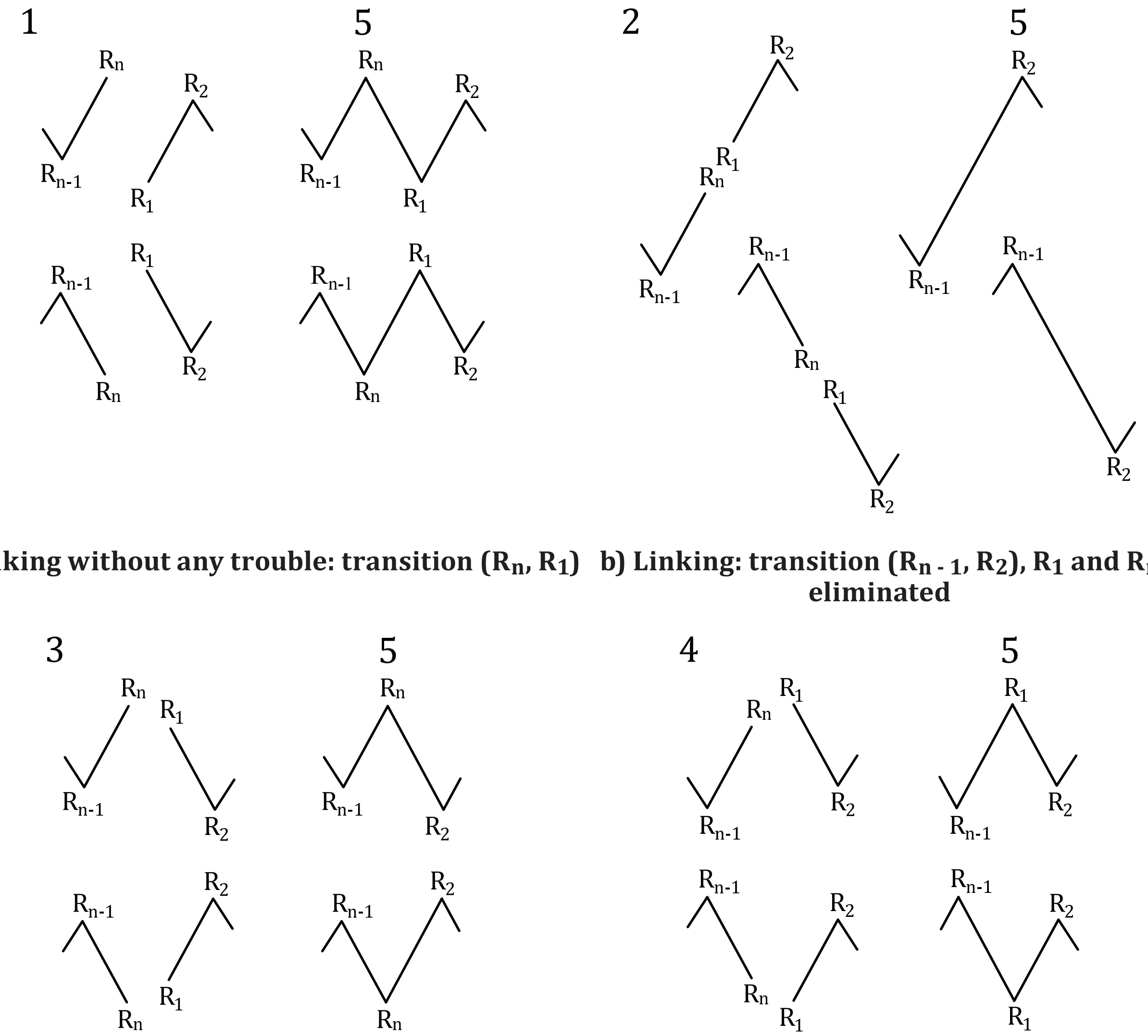
The interest of applying this procedure is that it uses the Rainflow counting method already used.

The whole signal fatigue loading signal is processed entirely to get a sequence of successive identical cycles.

When linking successive sequences of cycles, the following precautions shall be taken.

The last point of the open cycle sequence is followed by the first point of the entire loading sequence. These points may no more be considered as peaks or valleys. In this case, these points shall be eliminated.

Eight different cases may occur (see Figure A.10). To describe them explicitly, let's call R_1 and R_2 the two first points of the open cycle sequence and R_{n-1} and R_n the last two points.



a) Linking without any trouble: transition (R_n, R_1)

b) Linking: transition (R_{n-1}, R_2), R_1 and R_n eliminated

c) Linking: transition (R_n, R_2), R_1 is eliminated

d) Linking: transition (R_{n-1} – R_1), R_n is eliminated

Key

1 case encountered $(R_n - R_{n-1}).(R_2 - R_1) > 0$ and $(R_n - R_{n-1}).(R_1 - R_n) < 0$

2 case encountered $(R_n - R_{n-1}).(R_2 - R_1) > 0$ and $(R_n - R_{n-1}).(R_1 - R_n) \geq 0$

3 case encountered $(R_n - R_{n-1}).(R_2 - R_1) < 0$ and $(R_n - R_{n-1}).(R_1 - R_n) \geq 0$

4 case encountered $(R_n - R_{n-1}).(R_2 - R_1) < 0$ and $(R_n - R_{n-1}).(R_1 - R_n) < 0$

5 linking

Figure A.10 — Sequence linking cases

A.3.3.3 Closure of the open cycle sequence

The determination of the fatigue life requires that the loading signal can be regarded as a sequence of cycles. So, the open cycle sequence has to be treated to become a sequence of cycles.

The open cycle sequence is closed, moving the part of the signal from the beginning to the absolute maximum at the end of the sequence.

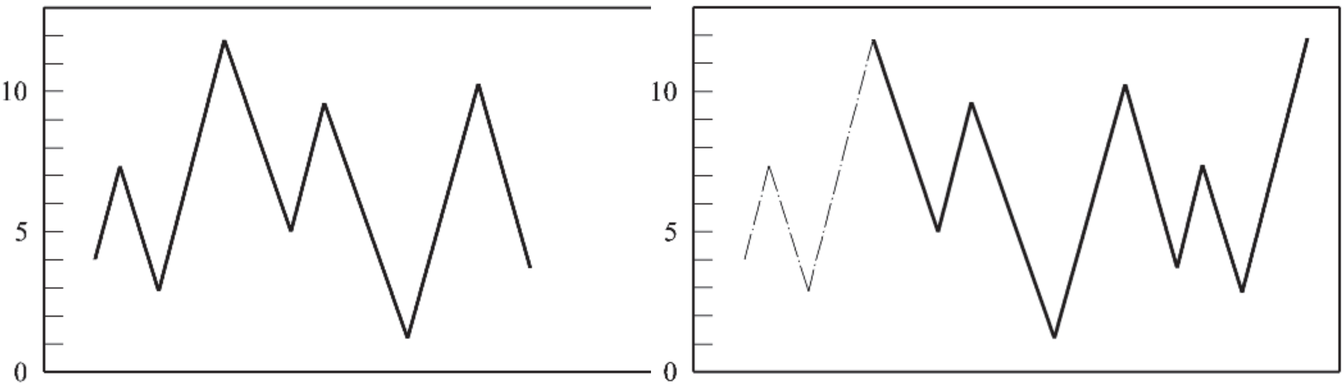


Figure A.11 — Closure of the open cycle sequence

Then, the Rainflow counting method is applied to the closed sequence.

A.3.4 Presentation of the results

A.3.4.1 Presentation in matrix form

The results of the counting are reported in matrixes “starting class-destination class” or “minimum value S_{min} – maximum value S_{max}”, or “amplitude S_a – mean value S_m”.

Depending on their subsequent use, the results can be presented following different matrix types. Five matrix types are described below:

1) Matrix [a_{ij}] “starting class-destination class» of the cycles as they are extracted and another one for the open cycle sequence. The recommended designation is: Rainflow matrix “starting class-destination class” of the cycles and open cycle sequence.

2) Matrix [b_{ij}] «starting class-destination class «of the cycles of the whole processed sequence, integrating the open cycle sequence. The recommended designation is: Rainflow matrix “starting class-destination class «of the cycles of the whole sequence.

3) Matrix [c_{ij}] “starting class-destination class” that shows all the transitions of the extracted cycles as well as those of the open cycle sequence. The recommended designation is: Rainflow matrix “starting class-destination class” of the transitions of the whole sequence.

This matrix resulting from a Rainflow counting is evidently different from the matrix of the transformation (Markov) of the original sequence.

The matrix [c_{ij}] can be derived from the matrix [a_{ij}] by the transformation

$$c_{ij} = a_{ij} + a_{ji} + \text{ transitions of the open cycle sequence} \quad (1)$$

The terms due to the open cycle sequence make this matrix non-symmetrical.

4) Matrix [d_{ij}] “minimum value S_{min} – maximum value S_{max}” of the cycles of the whole sequence, integrating the open cycle sequence.

The recommended designation is: Rainflow matrix “minimum value S_{min} – maximum value S_{max}” of the cycles of the whole sequence.

The matrix $[d_{ij}]$ is derived from the matrix $[b_{ij}]$ by the transformation:

$$d_{ij} = b_{ij} + b_{ji} \text{ if } i < j \quad (2)$$

$$d_{ij} = 0 \quad \text{if } i \geq j \quad (3)$$

The matrix $[d_{ij}]$ is strictly upper triangular.

5) Matrix $[e_{ij}]$ "mean value S_m – amplitude S_a" of the cycles of the whole sequence, integrating the open cycle sequence. The recommended designation is: Rainflow matrix "mean value S_m – amplitude S_a" of the cycles of the whole sequence.

This matrix contains [$(2k - 3)$ lines, $(k - 1)$ columns], where k is the number of representative levels.

For loading sequence reconstruction, the recommended matrix type is the first one.

For fatigue life evaluation, types 2, 4, and 5 can be used.

Type 3 serves to establish the diagram of the level exceedances from the Rainflow counting process.

A.3.4.2 Graphic representations

The presentation of the results in matrix form or three-dimensional diagrams (starting class, destination class, number of cycles), (minimum value S_{min}, maximum value S_{max}, numbers cycles) or (mean value S_m, amplitude S_a, number of cycles) is not practical, when one wants to represent the results graphically or to compare the features of several distributions.

Three different representations can be obtained from the result of the Rainflow counting:

— diagram of level exceedances;

— diagram of level exceedance ranges;

— diagram of Rainflow cycle ranges.

A.3.4.2.1 Diagram of level exceedances (see Tables C.1 and C.2)

One uses the class limit grid (see Clause 3).

One counts for each class limit the number of occurrences of when this limit is reached or exceeded by a valley-to-peak ascending loading. All ascending transitions of the extracted cycles and of the open cycle sequence are used.

The level exceedances diagram is obtained by putting the reached or exceeded limit on the y-axis and its occurrence number on the x-axis.

In simple cases, the diagram presents a higher branch and a lower branch.

This diagram is identical to the one obtained by the level exceedance counting method applied to the initial loading ("level crossing method").

A.3.4.2.2 Diagram of level exceedance ranges (see Table C.3)

In simple cases where the exceedance level diagram presents a higher branch and a lower one, another graphical representation can be derived from the previous diagram. The diagram of level exceedance ranges "level crossing range" is obtained while putting the range between the higher branch and the lower branch on the y-axis and the number of exceedances (or crossings) on the x-axis.

A.3.4.2.3 Diagram of Rainflow cycle ranges (see Table C.4)

This technique is applied to the results of the Rainflow counting method (cycles on the one hand and open cycle sequence on the other hand). Of each extracted cycle and of each ascending transition of the open cycle sequence, only its range is reported; thus, the mean value of the cycle or transition is not taken in account. The reported ranges are put on the y-axis and their cumulative frequencies are reported on the x-axis starting from the highest range to the lowest.

A.3.5 Combination of sequences and results of the Rainflow counting

In the case of a combined signal consisting in superimposed sequences, the result of the Rainflow counting of the combined signal does not correspond necessarily to the sum of the counting results of the individual sequences. Indeed, some of the cycles of the combined signal are derived from transitions including a peak or valley of one sequence and another peak or valley of another sequence.

When one wants to obtain the result of the Rainflow counting of a combined signal consisting in individual elementary sequences by using the Rainflow counting of each elementary signal, the methodology to follow is the following:

1) Express the Rainflow counting results of each elementary sequence according to the first type of presentation: “extracted cycles + open cycle sequence”.

2) Construct a signal connecting the open cycle sequences of each sequence, following the order of occurrence in the combined signal.

3) Process entirely this signal to obtain cycles (open cycle sequence included).

4) The Rainflow counting result of the combined signal is obtained by adding the extracted cycles of the previous step (3) and those extracted in the first step (1).

This methodology requires that the representative values of the levels of the different sequences constitute compatible grids (identical class heights, values).

Annex B
(informative)

Examples of quantification, cycle extraction, and open cycle sequence composition of cycles

B.1 Example

As an example, let's suppose that the extraction of the peaks and valleys leads to the signal indicated in Table B.1.

Table B.1 — Examples of peak and valley extraction

Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14
Load	4,2	7,3	2,0	9,8	9,6	10,3	5,2	8,5	3,0	4,4	2,2	2,4	2,2	12,0
Point	15	16	17	18	19	20	21	22	23	24	25	26	27	28
Load	5,5	11,1	1,0	4,3	3,5	9,5	6,0	12,0	3,9	8,3	1,2	8,6	3,9	6,2

B.2 Quantification of the values of the signal

For clarity of presentation, the number of classes is limited to 12. The 12 representative levels of these classes are taken in the middle of the classes.

The minimum value of the signal (1,0) and the maximum value of the signal (12,0) are considered as the representative values of the first class and of the 12th class, respectively.

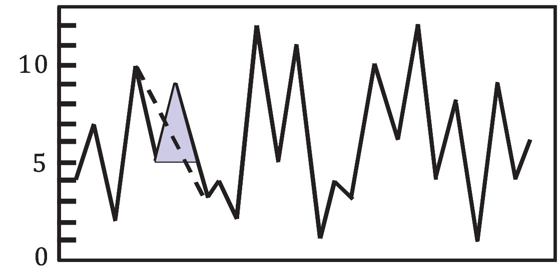
The signal after quantification consists in the succession of the 24 peaks and valleys presented in Table B.2.

Table B.2 — Quantification of the values of the signal

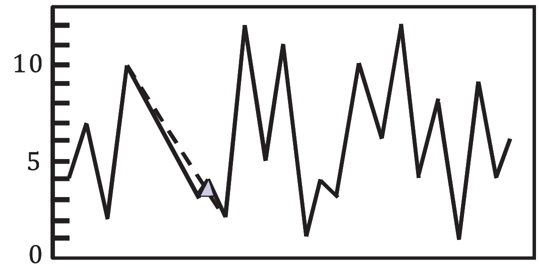
Point	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21	22	23	24
Load	4	7	2	10	5	9	3	4	2	12	5	11	1	4	3	10	6	12	4	8	1	9	4	6

B.3 Extraction of the cycles [Figures B.1 a) to B.1 i)]

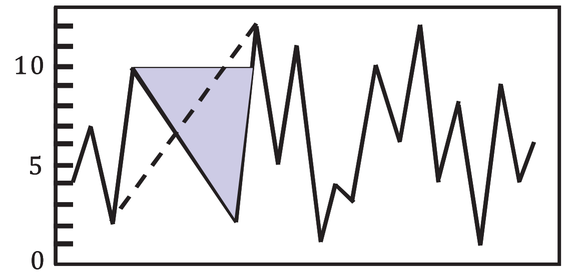
The representative class values are reported in ordinate axes in the following graphs.



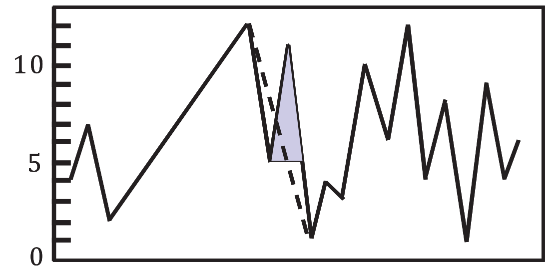
a) Extracted cycle: 5-9



b) Extracted cycle: 3-4

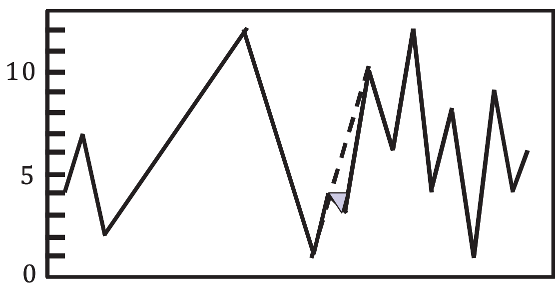


c) Extracted cycle: 10-2

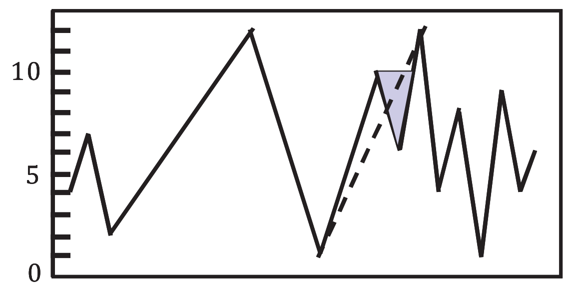


d) Extracted cycle: 5-11

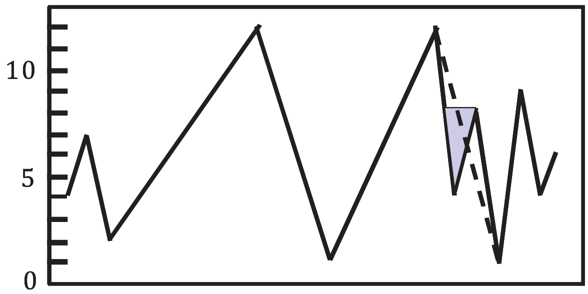
Figure B.1 — *(continued)*



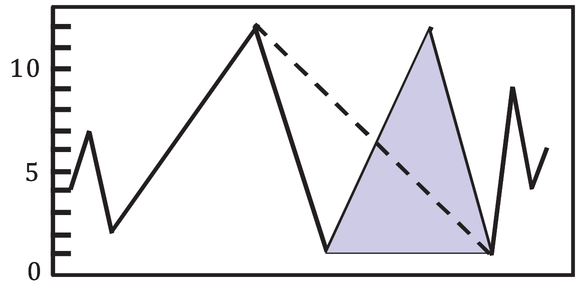
e) Extracted cycle: 4-3



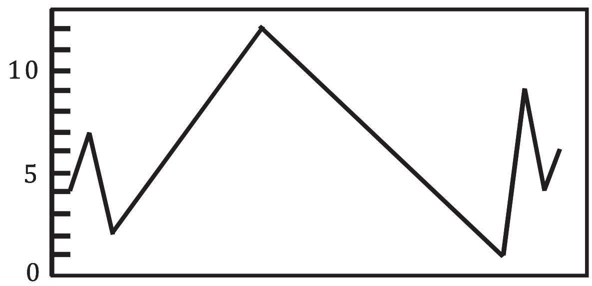
f) Extracted cycle: 10-6



g) Extracted cycle: 4-8



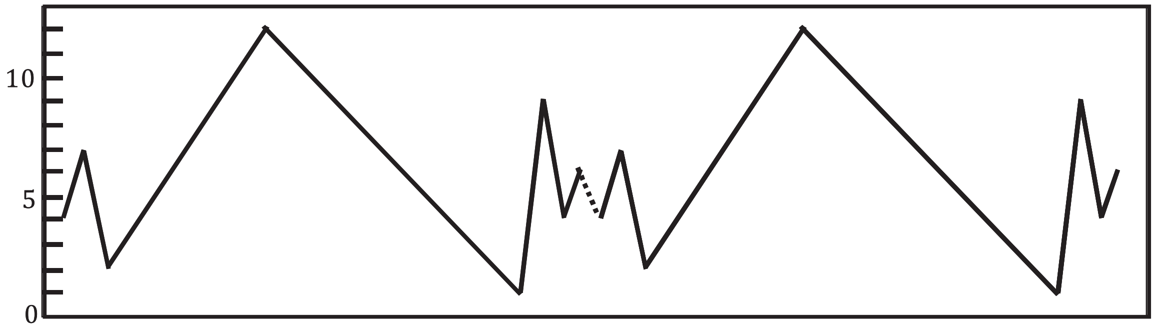
h) Extracted cycle: 1-12



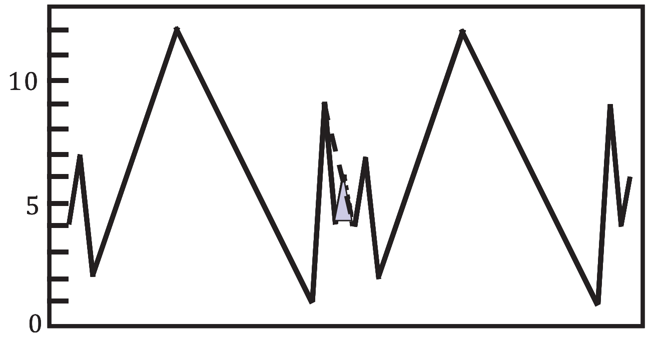
i) Open cycle sequence: 4-7-2-12-1-9-4-6

Figure B.1 — Extraction of the cycles

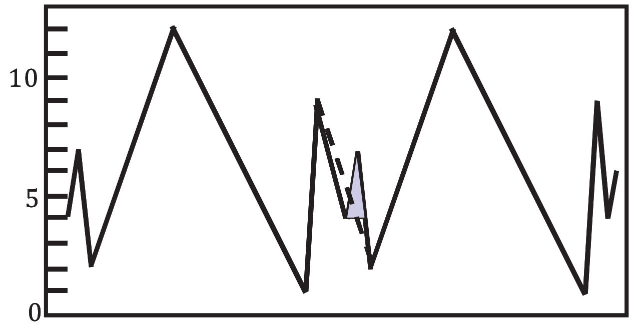
B.4 Treatment of the open cycle sequence — Decomposition in cycles [Figures B.2 a) to B.2 f)]



a) Signal used for the treatment of the open cycle sequence (duplication of the open cycle sequence)

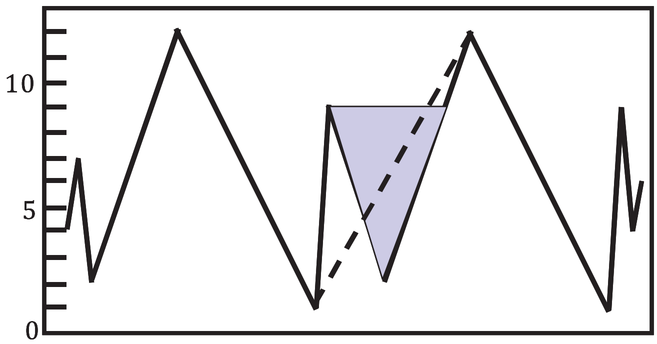


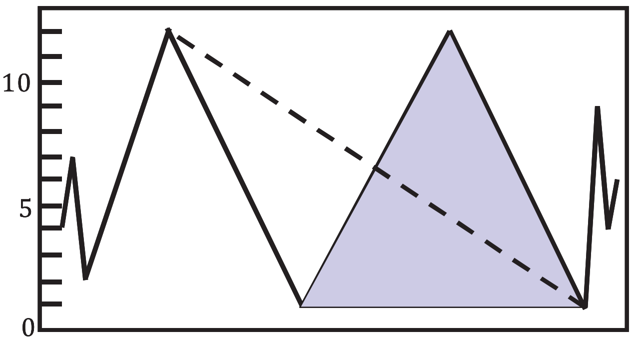
b) Extracted cycle: 4-6



c) Extracted cycle: 4-7

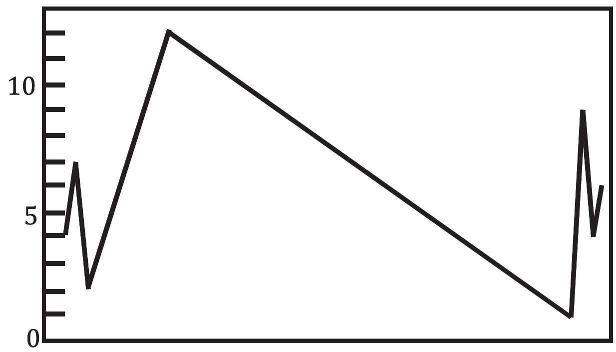
Figure B.2 — *(continued)*





d) Extracted cycle: 9-2

e) Extracted cycle: 1-12



f) Open cycle sequence: 4-7-2-12-1-9-4-6

Figure B.2 — Treatment of the open cycle sequence — Decomposition in cycles

The open cycle sequence obtained at the end of treatment is identical to the initial open cycle sequence.

All 12 extracted cycles: 5-9; 3-4; 10-2; 5-11; 4-3; 10-6; 4-8; 1-12; 4-6; 4-7; 9-2; 1-12.

Annex C
(informative)

Example of result presentation for the Rainflow counting method

C.1 Example of result presentation

Table C.1 — Rainflow matrix (a_{ij}) "starting class – destination class" + open cycle sequence

Starting class

Destination class	1	2	3	4	5	6	7	8	9	10	11	12
1												1
2												
3				1								
4			1					1				
5									1		1	
6												
7												
8												
9												
10		1				1						
11												
12												

Open cycle sequence: 4-7-2-12-1-9-4-6

Table C.2 — Rainflow matrix (b_{ij}) "starting class – destination class" of the cycles of the whole sequence

Starting class

Destination class	1	2	3	4	5	6	7	8	9	10	11	12
1												1+(1)
2												
3				1								
4			1			(1)	(1)	1				
5									1		1	
6												
7												
8												
9		(1)										
10		1				1						
11												
12												

(x) : cycles extracted from the open cycle sequence

Table C.3 — Rainflow matrix (c_{ij}) "starting class – destination class" of the transitions of the whole sequence

Starting class

Destination class	1	2	3	4	5	6	7	8	9	10	11	12
1									(1)			1
2										1		(1)
3				2								
4			2			(1)	(1)	1				
5									1		1	
6										1		
7		(1)										
8				1								
9				(1)	1							
10		1				1						
11					1							
12	1+(1)											

(x) : Open cycle sequence

Table C.4 — Rainflow matrix (d_{ij}) "minimum value S_{min} – maximum value S_{max}" of the cycles of the whole sequence

Maximum value Smax

Minimum value Smin	1	2	3	4	5	6	7	8	9	10	11	12
1												2
2									1	1		
3				2								
4						1	1	1				
5									1		1	
6										1		
7												
8												
9												
10												
11												
12	1+(1)											

Table C.5 — Rainflow matrix (e_{ij}) "mean value S_m — amplitude S_{max}" of the cycles of the whole sequence

Mean value S_m	Amplitude S_a										
	0,5	**1**	**1,5**	**2**	**2,5**	**3**	**3,5**	**4**	**4,58**	**5**	**5,5**
1,5											
2											
2,5											
3											
3,5	2										
4											
4,5											
5		1									
5,5			1				1				
6				1				1			
6,5											2
7		1									
7,5											
8		1				1					
8,5											
9											
9,5											
10											
10,5											
11											
11,5											

C.2 Graphical representations

C.2.1 Exceedance level diagram

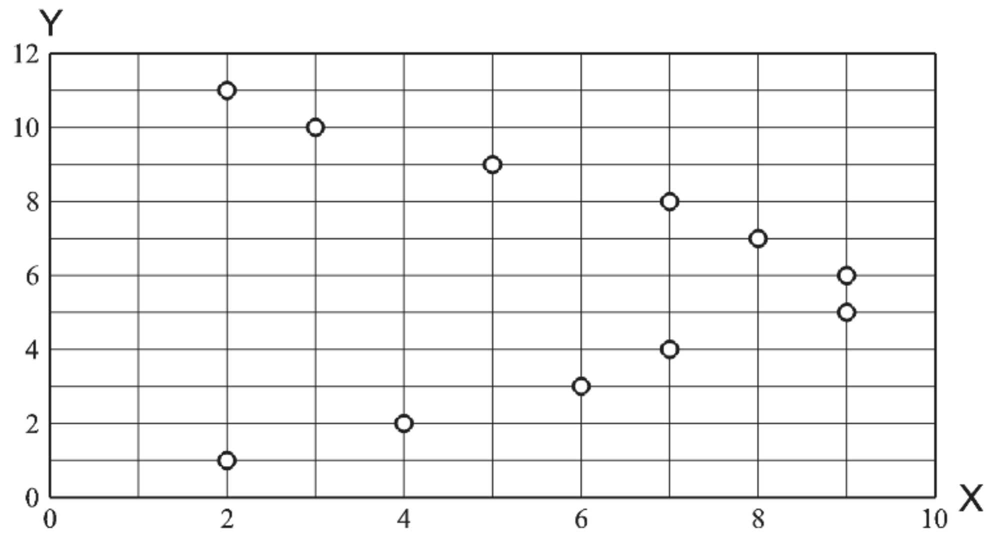
Table C.6 — Level exceedances derived from the Rainflow counting process

Exceedance level													Number of exceedances
1’								*			+		2
2’			*					*		+	+		4
3’		*	*		*			*		+	+		6
4’			*				*	*	+	+	+	+	7
5’	*		*	*			*	*	+	+	+	+	9
6’	*		*	*		*	*	*	+	+	+		9
7’	*		*	*		*	*	*		+	+		8
8’	*		*	*		*		*		+	+		7
9’			*	*		*		*		+			5
10’				*				*		+			3
11’								*		+			2

* cycles

\+ open cycle sequence

Each of the extracted cycles and each of the ascending transitions of the open cycle sequence appear in the column of Table C.6 in their order of occurrence.



Key

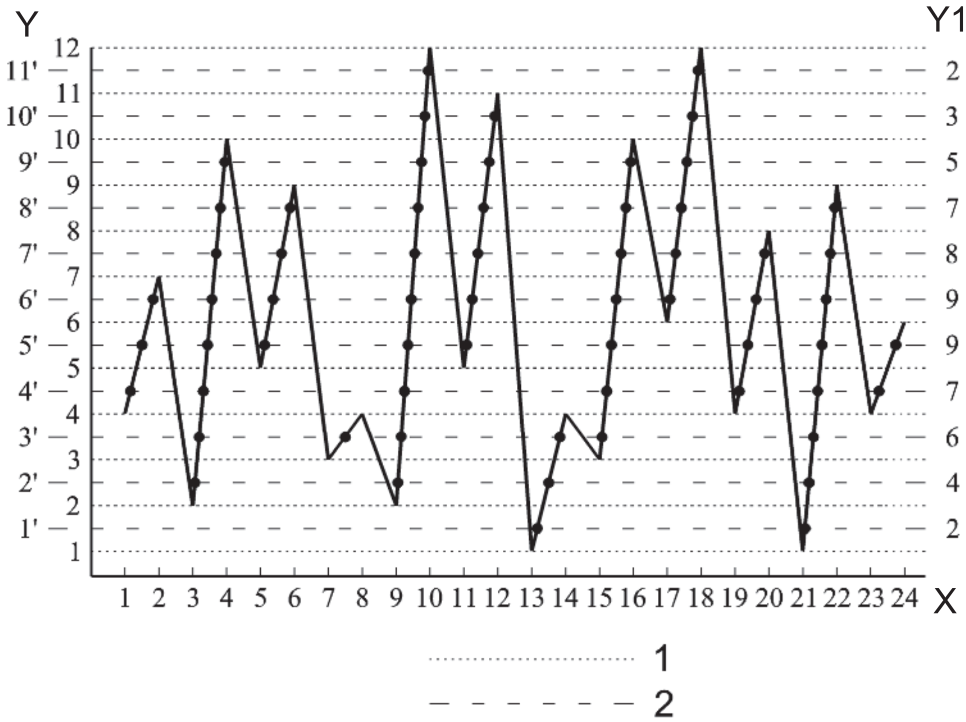
X number of level exceedances

Y level

Figure C.1 — Level exceedance diagram

The level exceedances obtained from the original sequence are indicated in Figure C.2.

The ascending transition exceedances are counted.



Key

X time

Y load

Y1 number of exceedances

1 representative level of the class (quantified value)

2 class limit

Figure C.2 — Level exceedances obtained from the original sequence

The level exceedances derived from the Rainflow counting are rigorously identical to those obtained directly from the original sequence.

C.2.1.1 Diagram of the level exceedance ranges

The number of level exceedance ranges can be determined.

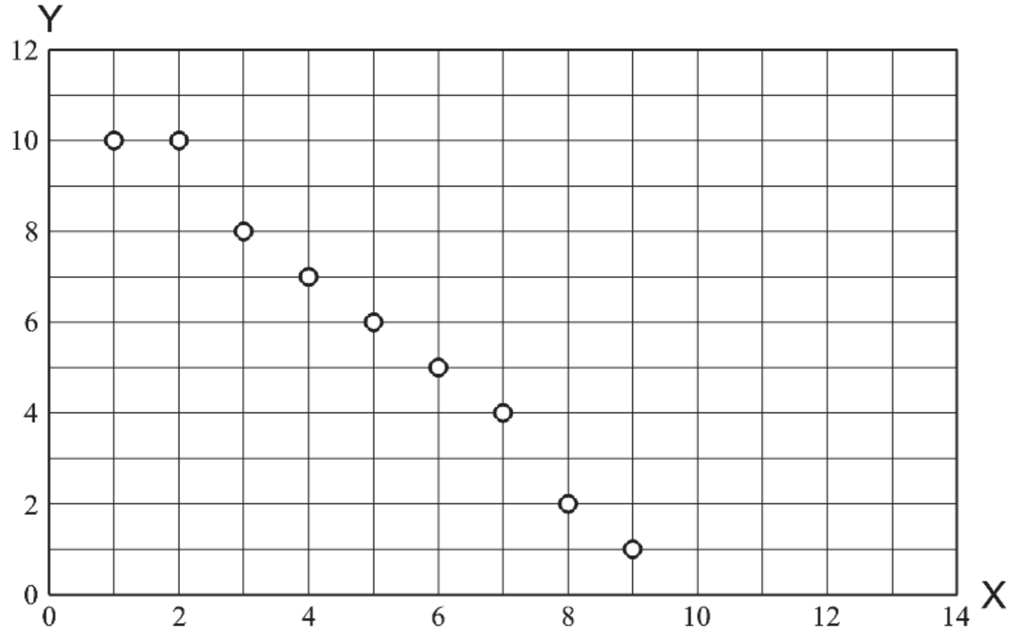
If the open cycle sequence is not distinguished from the rest, one gets the representation reported in Table C.7.

Table C.7 — Rainflow cycle ranges

Range value													Number of ranges
1	*	*	*	*	*	*	*	*	+	+	+	+	12
2	*		*	*		*	*	*	+	+	+	+	10
3	*		*	*		*	*	*	+	+	+		9
4	*		*	*		*	*	*		+	+		8
5			*	*				*		+	+		
6			*	*				*		+	+		5
7			*					*		+	+		
8			*					*		+	+		4
9								*		+			
10								*		+			2
11								*					1

* cycles

\+ open cycle sequence



Key

X number of exceedances

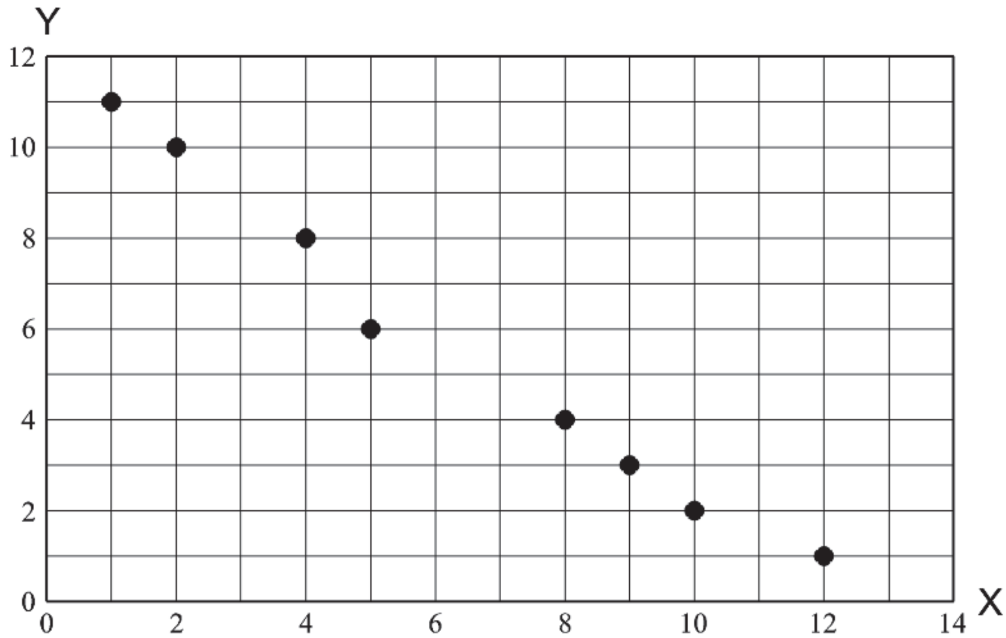
Y level exceedances range

Figure C.3 — Level exceedance ranges diagram

C.2.2 Rainflow cycle range diagram

Table C.8 — Level exceedance ranges derived from the Rainflow counting process

Exceedance level	**Number of exceedances**									
	1	2	3	4	5	6	7	8	9	10
1’	*	*								
2’	*	*	*	*						+
3’	*	*	*	*	*	*				
4’	*	*	*	*	*	*	*			
5’	*	*	*	*	*	*	*	*	*	
6’	*	*	*	*	*	*	*	*	*	
7’	*	*	*	*	*	*	*	*		
8’	*	*	*	*	*	*	*			
9’	*	*	*	*	*					
10’	*	*	*							
11’	*	*								
Exceedances ranges	10	10	8	7	6	5	4	2	1	



Key

X cumulative frequency of ranges

Y rainflow range

Figure C.4 — Rainflow cycle range diagram

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