IEC TR*1463 96 ■ 4844891 0627291 142 ■

RAPPORT TECHNIQUE

TECHNICAL REPORT

CEI
IEC
1463

Première édition
First edition
1996-07

Traversées – Qualification sismique

Bushings – Seismic qualification

IEC

Numéro de référence
Reference number
CEI/IEC 1463: 1996

RAPPORT TECHNIQUE – TYPE 2

TECHNICAL REPORT – TYPE 2

CEI
IEC
1463

Première édition
First edition
1996-07

Traversées – Qualification sismique

Bushings – Seismic qualification

Bureau central de la Commission Electrotechnique Internationale 3, rue de Varembé Genève Suisse

IEC

Commission Electrotechnique Internationale
International Electrotechnical Commission
Международная Электротехническая Комиссия

CODE PRIX
PRICE CODE V

Pour prix, voir catalogue en vigueur
For price, see current catalogue

CONTENTS

INTERNATIONAL ELECTROTECHNICAL COMMISSION

BUSHINGS – SEISMIC QUALIFICATION

FOREWORD

1) The IEC (International Electrotechnical Commission) is a worldwide organization for standardization comprising all national electrotechnical committees (IEC National Committees). The object of the IEC is to promote international co-operation on all questions concerning standardization in the electrical and electronic fields. To this end and in addition to other activities, the IEC publishes International Standards. Their preparation is entrusted to technical committees; any IEC National Committee interested in the subject dealt with may participate in this preparatory work. International, governmental and non-governmental organizations liaising with the IEC also participate in this preparation. The IEC collaborates closely with the International Organization for Standardization (ISO) in accordance with conditions determined by agreement between the two organizations.

2) The formal decisions or agreements of the IEC on technical matters express, as nearly as possible, an international consensus of opinion on the relevant subjects since each technical committee has representation from all interested National Committees.

3) The documents produced have the form of recommendations for international use and are published in the form of standards, technical reports or guides and they are accepted by the National Committees in that sense.

4) In order to promote international unification, IEC National Committees undertake to apply IEC International Standards transparently to the maximum extent possible in their national and regional standards. Any divergence between the IEC Standard and the corresponding national or regional standard shall be clearly indicated in the latter.

5) The IEC provides no marking procedure to indicate its approval and cannot be rendered responsible for any equipment declared to be in conformity with one of its standards.

6) Attention is drawn to the possibility that some of the elements of this International Standard may be the subject of patent rights. IEC shall not be held responsible for identifying any or all such patent rights.

The main task of IEC technical committees is to prepare International Standards. In exceptional circumstances, a technical committee may propose the publication of a technical report of one of the following types:

- type 1, when the required support cannot be obtained for the publication of an International Standard, despite repeated efforts;
- type 2, when the subject is still under technical development or where for any other reason there is the future but no immediate possibility of an agreement on an International Standard;
- type 3, when a technical committee has collected data of a different kind from that which is normally published as an International Standard, for example "state of the art".

Technical reports of types 1 and 2 are subject to review within three years of publication to decide whether they can be transformed into International Standards. Technical reports of type 3 do not necessarily have to be reviewed until the data they provide are considered to be no longer valid or useful.

IEC 1463, which is a technical report of type 2, has been prepared by sub-committee 36A: Insulated bushings, of IEC technical committee 36: Insulators.

The text of this technical report is based on the following documents:

Committee draft	Report on voting
36A/48/CDV	36A/56/RVC

Full information on the voting for the approval of this technical report can be found in the report on voting indicated in the above table.

This document is issued in the type 2 technical report series of publications (according to G.3.2.2 of part 1 of the IEC/ISO Directives) as a "prospective standard for provisional application" in the field of bushings because there is an urgent requirement for guidance on how standards in this field should be used to meet an identified need.

This document is not to be regarded as an "International Standard". It is proposed for provisional application so that information and experience of its use in practice may be gathered. Comments on the content of this document should be sent to the IEC Central Office.

A review of this type 2 of technical report will be carried out not later than three years after its publication, with the options of either extension for a further three years or conversion to an International Standard or withdrawal.

Annexes A, B, C and D are for information only.

INTRODUCTION

As it is not always possible to define accurately the seismic severity at the bushing flange level, this technical report presents three alternative methods of qualification. The three methods are equally acceptable. If the Required Response Spectrum (RRS) at the bushing flange is not known, a severity (in terms of acceleration values) based on standard response spectra at the ground level may be used to carry out qualification through one of the three methods described in the present technical report.

When the environmental characteristics are not sufficiently known, qualification by static calculation is acceptable. Where high safety reliability of equipment is required for a specific environment, the use of precise data is necessary, therefore qualification by dynamic analysis or vibration test is recommended. The choice between vibration testing and dynamic analysis depends mainly on the capacity of the test facility for the mass and volume of the specimen, and, also if non-linearities are expected.

When qualification by dynamic analysis is foreseen, it is recommended that the numerical model be adjusted by using vibration data (see clause 5).

This type 2 technical report was prepared with the intention of being applicable to bushings whatever their construction material. However, the information contained hereafter is more specifically directed to porcelain bushings. The application of this type 2 technical report to composite bushings can be done after appropriate adjustment of parameters and criteria.

BUSHINGS – SEISMIC QUALIFICATION

1 Scope

This technical report is applicable to alternating current and direct current bushings for rated voltages above 52 kV, mounted on transformers, other apparatus or buildings. It is accepted that for bushings for rated voltages less than or equal to 52 kV, due to their characteristics (resonance frequency greater than 25 Hz) seismic qualification is not required.

This technical report presents acceptable seismic qualification methods and requirements to demonstrate that a bushing can maintain its mechanical properties, insulate and carry current during and after an earthquake.

The seismic qualification of a bushing is only performed upon request.

2 Normative references

The following normative documents contain provisions which, through reference in this text constitute provisions of this technical report. At the time of publication, the editions indicated were valid. All normative documents are subject to revision, and parties to agreements based on this technical report are encouraged to investigate the possibility of applying the most recent editions of the normative documents indicated below. Members of IEC and ISO maintain registers of currently valid International Standards.

IEC 68-2-6: 1995, *Environmental testing – Part 2: Tests – Test Fc: Vibration (sinusoidal)*

IEC 68-2-47: 1982, *Basic environmental testing procedures – Part 2: Tests – Mounting of components, equipment and other articles for dynamic tests including shock (Ea), bump (Eb), vibration (Fc and Fd) and steady-state acceleration (Ga) and guidance*

IEC 68-2-57: 1989, *Environmental testing – Part 2: Test methods – Test Ff: Vibration – Time-history method*

IEC 68-2-59: 1990, *Environmental testing – Part 2: Test methods – Test Fe: Vibration – Sine-beat method*

IEC 68-3-3: 1991, *Environmental testing – Part 3: Guidance – Seismic test methods for equipments*

IEC 137: 1995, *Insulated bushings for alternating voltages above 1 000 V*

IEC 721-2-6: 1990, *Classification of environmental conditions – Part 2: Environmental conditions appearing in nature – Earthquake vibration and shock*

IEC 1166: 1993, *High-voltage alternating current circuit-breakers – Guide for seismic qualification of high-voltage alternating current circuit-breakers*

IEC 1264: 1994, *Ceramic pressurized hollow insulators for high-voltage switchgear and controlgear*

ISO 2041: 1990, *Vibration and shock – Vocabulary*

3 Definitions

For the purpose of this technical report the definitions of IEC 68-3-3 and ISO 2041, and the following definitions apply:

3.1 **critical cross-section:** Section of the bushing that is most likely to fail during an earthquake.

3.2 **response spectrum:** Plot of the maximum response to a defined input motion of a family of single-degree-of-freedom bodies at a specified damping ratio. (ISO 2041, modified)

3.3 **rigid equipment:** Equipment whose natural frequency is greater than 25 Hz is considered rigid for the purpose of this technical report.

4 Symbols and abbreviations

a_{bg} Equivalent maximum acceleration to the centre of gravity of the bushing during the seismic event

a_{cg} Actual acceleration of the centre of gravity of the bushing relative to its flange

a_f Maximum acceleration of the bushing flange

a_g Maximum acceleration of the ground resulting from the motion of a given earthquake

NOTE – a_g is equal to the Zero Period Acceleration (ZPA) of figure 1.

d_p Distance between the centre of gravity of the part of the bushing which is under consideration and the critical cross-section

f First natural frequency of the mounted bushing

K Superelevation factor between ground and bushing flange: factor accounting for the change in the acceleration from the ground to the flange due to the amplification by buildings and structures

m_p Mass of the part of the bushing which is under consideration

M_s Bending moment at the critical cross-section of the part of the bushing considered, due to an earthquake

R Response factor derived from the Required Response Spectrum (RRS) as the ratio between the response acceleration and the ZPA (see figure 2)

RRS Required Response Spectrum: response spectrum specified by the user

S_c Coefficient established to take into account the effects of both multifrequency excitation and multimode response

ZPA Zero Period Acceleration (see a_g)

5 Methods of seismic qualification

Seismic qualification should demonstrate the ability of a bushing to withstand seismic stresses and to maintain its required function without failure, during and after an earthquake of a specified severity (clause 6).

As bushings are mounted on apparatus or buildings, the seismic qualification of the bushing must consider the behaviour of the apparatus or building. In the seismic qualification of a bushing all parts should be included, which contribute to the stresses in the critical cross-sections during a seismic event, e.g. the conductor and inner spacer in gas insulated bushings.

Three methods and combinations thereof are described in this technical report:

- qualification by static calculation (clause 7);
- qualification by dynamic analysis (clause 8);
- qualification by vibration test (clause 9).

A combination of the methods may be used:

- to qualify a bushing which cannot be qualified by testing alone (e.g. because of size and/or complexity of the apparatus);
- to qualify a bushing already tested under different seismic conditions;
- to qualify a bushing similar to a bushing already tested but which includes modifications influencing the dynamic behaviour (e.g. change in the length of insulators or in the mass).

Vibrational data (damping, critical frequencies, stresses of critical elements as a function of input acceleration) for analysis can be obtained by:

a) a dynamic test on a similar bushing;

b) a dynamic test at reduced test level;

c) determination of natural frequencies and damping by other tests such as free oscillation tests (see annex B) or low level excitation (see clause A.10 of IEC 1166).

The methods result in the value of M_s which is determined for each part of the bushing on either side of the flange. The stress due to this moment should be combined with the other stresses acting in the bushing and it should be demonstrated that the bushing withstands the combined stress (clause 10).

The different methods of seismic qualification are illustrated in the flow chart given in annex A.

6 Severities

6.1 *At the ground*

The ground acceleration depends upon the seismic conditions of the site where the apparatus is to be located. When it is known, it should be prescribed by the relevant specification. Otherwise the severity level should be selected from table 1.

Table 1 – Ground acceleration levels

Ground acceleration reference	Description of earthquake					
	General	a_g m/s²	Richter scale magnitude	UBC zone[1)]	Intensity MSK[2)]	RRS
AG2	Light to medium earthquakes	2	<5,5	1-2	<VIII	figure 1[3)]
AG3	Medium to strong earthquakes	3	5,5 to 7,0	3	VIII to IX	figure 1[3)]
AG5	Strong to very strong earthquakes	5	>7,0	4	>IX	figure 1

1) Approximate Uniform Building Code zone (International conference of building officials).

2) MSK (Medvedev-Sponheuer-Karnik) corresponds to modified Mercalli intensity scale.

3) Values for AG2 and AG3 are obtained by multiplying the values from figure 1 by 2/5 and 3/5 respectively.

The selected qualification level should be in accordance with expected earthquakes of maximum ground motions for the site location. This level corresponds to S_2 earthquakes (see 3.24 of IEC 68-3-3).

For qualification it should be assumed that:

- the horizontal movements as described in table 1 act in any direction ;
- the severities of the vertical accelerations are 50 % of the horizontal;
- both directions may reach their maximum values simultaneously.

The ground motion can be described by natural time histories when known, or by artificial time histories, which should comply with the RRS; this is used as input for dynamic analysis or vibration test on the complete apparatus.

NOTE – Information on the correlation between seismic qualification levels, seismic zone and seismic scales are given in IEC 721-2-6 and IEC 68-3-3.

6.2 *At the bushing flange*

The severity at the bushing flange (see figure 4) may be available from the manufacturer of the apparatus and structures (i.e. transformers, gas insulated substations (GIS), building) in terms of RRS or maximum acceleration (a_f). Where no information is available, the following simplified formula is used in order to establish an acceleration value at the flange of the bushing.

$$a_f = K \times a_g$$

The superelevation factor K can be:

- calculated by finite element analysis including soil interaction or any other careful modelling, or
- derived from results from calculations or tests on comparable apparatus or structures, or
- taken from typical values obtained from experience. So far very little experience is reported. Unless more background information is available, K should be assumed to be 1,5. See also 8.2.5 of IEC 68-3-3, table 4.

7 Qualification by static calculation

This method is valid for rigid equipment. It may be extended to flexible equipment, such as a bushing, taking into consideration the response factor R, as an alternative to the method by analysis. This allows simpler evaluation with increased conservatism.

Using the static calculation method, the bending moment in the critical cross-section of the part of the bushing under consideration is calculated from an equivalent acceleration of the centre of gravity of that part:

$$M_s = a_{bg} \times d_p \times m_p$$

This acceleration, a_{bg}, is calculated from the flange acceleration a_f by multiplication with a coefficient and the response factor (see annex C):

$$a_{bg} = a_f \times S_c \times R$$

The value of S_c depends on the natural frequency of the mounted bushing:

$f \leq 9$ Hz	$S_c = 1{,}5$
$9 < f < 25$ Hz	$S_c = 1 + 0{,}5 \times (25 - f) / (25-9)$
$f \geq 25$ Hz	$S_c = 1{,}0$

If the natural frequency is not known, the conservative value $S_c = 1{,}5$ should be used.

The value R can be established by one of the following methods.

a) From the spectrum at the bushing flange (if available).

b) When the spectrum at the bushing flange is not known, the spectrum at the ground (figure 1) may be used assuming that the levels at all frequencies are equally amplified (K factor) from the ground to the flange. For such cases the values of R are summarized in figure 2.

It is necessary to know the first natural frequency and the damping of the bushing mounted on its supporting structure. The natural frequency can either be calculated as indicated for the superelevation factor or found by a free oscillation test as described in annex B.

c) R may be assumed to be equal to 1,74 when information for frequency and damping of the bushing mounted on a transformer is not available. The value of 1,74 corresponds to the frequency range 2,4 Hz to 9 Hz and 5 % damping ratio.

d) R may be assumed to be equal to 2,25 when information for frequency and damping of the bushing mounted on a GIS structure is not available. The value of 2,25 corresponds to the frequency range 2,4 Hz to 9 Hz and 3 % damping ratio.

Collected data show that the first natural frequency of a mounted bushing is lower than that of the bushing itself. Reported natural frequencies show a great variation, while the damping ratios lie within a limited range, see table 2.

An example of the application of the method for bushings mounted on a transformer is given in annex D.

Table 2 – Dynamic parameters obtained from experience on bushings with porcelain insulators

Type of mounting	Rated voltage of bushing					
	123 kV to 170 kV		245 kV		420 kV to 500 kV	
	Frequency Hz	Damping ratio %	Frequency Hz	Damping ratio %	Frequency Hz	Damping ratio %
Bushing alone (mounted on a rigid structure)	15 to 35	2 to 4	10 to 20	2 to 4	5 to 15	2 to 4
Bushing mounted on a transformer tank	8 to 20	5	5 to 15	5	3 to 8	5
Bushing mounted on a GIS	4 to 7	3 to 5	–	–	–	–
Bushing mounted on a building	–	–	–	–	–	–

NOTES

1 In the case of special dissipating systems, higher damping ratios may be obtained.

2 Additional data will be included in this table based on experience of the practical application of this technical report.

8 Qualification by dynamic analysis

For dynamic analysis the whole structure, the apparatus and the ground conditions including foundations, with the mounted bushing should be modelled by finite elements or other mathematical modelling technique, taking into consideration the specific values of elasticity and damping of all elements as well as the relevant masses. The structure may be assumed to behave linearly and elastically except special seismic equipment (see last paragraph of 10.3), which should be modelled with its actual properties. The linear values used should correspond to the values expected at the seismic load level.

From the calculation the stresses in the critical cross-section of the bushing can be found.

A dynamic analysis may be performed on a bushing alone if the flange severity is already known.

The general procedure is to establish, using experimental data, a mathematical model of the structure in order to assess its dynamic characteristics and then to determine the response, using either of the methods described in the following subclauses. Other methods may be used if they can be justified.

8.1 *Modal analysis using the time-history method*

When the time-history method is used for seismic analysis, the ground motion acceleration time-histories should comply with the RRS (see table 1). Two types of superimposition may generally be applied depending on the complexity of the problem:

– separate calculation of the maximum responses due to each of the three directions (*x* and *y* in the horizontal, and *z* in the vertical direction) of the earthquake. These maximum values are then combined by taking the square root of the sum of the squares, i.e. $(x^2 + z^2)^{1/2}$ and $(y^2 + z^2)^{1/2}$. The greater of these two values is used for the combination of the stresses of the bushing;

– simultaneous calculation of one of the horizontal directions and the vertical direction (*x* with *z*) and, thereafter, calculation of the other horizontal direction and the vertical direction (*y* with *z*). This means that, after each step of calculation, all values (force, stresses) are superimposed algebraically. The greater of these two values is used for the combination of the stresses of the bushing.

8.2 *Modal analysis using the RRS*

When the RRS method is used for seismic analysis, the procedure of combining the stresses is described for an orthogonal system of co-ordinates in the main axes of the bushing and with *x* and *y* in the horizontal and *z* in the vertical direction. The maximum values of stresses in the bushing for each of the three directions *x*, *y* and *z* are obtained by superimposing the stresses calculated for the various modal frequencies in each of these directions by taking the square root of the sum of the squares. The maximum values in the *x* and *z* direction - and in the *y* and *z* direction - are obtained by taking the square root of the sum of the squares. The greater value of these two cases (*x*, *z*) or (*y*, *z*) is used for the combination of the stresses of the bushing.

9 Qualification by vibration test

9.1 *General*

Three different approaches can be applied:

- test on the complete apparatus (bushing mounted on the real apparatus);
- test on the bushing mounted on a simulating support;
- test on the bushing alone.

The procedure for qualification by test should be in accordance with clauses 11 to 15 of IEC 68-3-3, IEC 68-2-57 and IEC 68-2-59. The tests should be made at the ambient air temperature of the test location and this temperature should be recorded in the test report. After the vibration test, the bushing should pass a routine test according to clause 8 of IEC 137.

9.1.1 *Mounting*

General mounting requirements are given in IEC 68-2-47. The specimen should be mounted as in service including dampers (if any).

NOTE – For more detailed guidance in the case of equipment normally used with vibration isolators, see clause A.5 of IEC 68-2-6.

The orientation and mounting of the specimen during conditioning should be prescribed by the relevant standard. They are the only condition for which the specimen is considered as complying with the requirements of the standard, unless adequate justification can be given for extension to an untested condition (for instance, if it is proved that the effects of gravity do not influence the behaviour of the specimen).

9.1.2 *External load*

Generally, electrical and environmental service loads cannot be simulated during the seismic test. This applies also to possible internal pressure of the bushing due to safety requirements of the test laboratory.

NOTE – For combination of seismic and service loads, see clause 10.

9.1.3 *Measurements*

Measurements should be performed in accordance with 5.2 of IEC 68-3-3, and should include:

- vibration motion of the centre of gravity of the bushing;
- strains on critical cross-sections.

9.1.4 *Frequency range*

The frequency range should be 1 Hz to 35 Hz.

9.1.5 *Test methods*

The test methods should be:

- time-history, or
- sine-beat, or
- other waveforms, e.g. sine wave (requiring justification).

9.1.5.1 *Parameters for time-history*

The total duration of the time-history should be about 30 s of which the strong part should be not less than 15 s. The test method should be in accordance with IEC 68-2-57.

9.1.5.2 *Parameters for sine-beat*

Test frequencies should cover the frequency range stated in 9.1.4 with half octave spacing, and should include the resonance frequencies of the specimen. The test method should be in accordance with IEC 68-2-59.

9.1.6 *Testing*

9.1.6.1 *Test axes*

The test axes should be chosen according to 3.19 of IEC 68-3-3. In some cases the effect of the vertical acceleration results in negligible stresses and the vertical excitation may be omitted.

9.1.6.2 *Test sequence*

The test sequence should be as follows.

a) *Vibration response investigation*

The vibration response investigation should be carried out according to 10.1 and 14.2 of IEC 68-3-3 over the frequency range stated in 9.1.4.

b) *Seismic qualification test*

The test should be performed by applying one of the procedures stated in flow chart A.3 (except test Fc) or flow chart A.4 of IEC 68-3-3 depending on the test facilities.

The test should be performed once at the level chosen in clause 6.

During the seismic test the measurements as stated in 9.1.3 should be recorded.

9.2 *Test on complete apparatus*

When the size and/or complexity of the apparatus allow assembly on the shaker table, a test on the complete apparatus is recommended.

The test severity should be chosen in accordance with 6.1. The time-history method is recommended since it more closely simulates the actual conditions, particularly if the behaviour of the specimen under test is not linear.

9.3 *Test on the bushing mounted on a simulating support*

The bushing is mounted on a simulating support which is fastened to a shaker table (see figure 3). The simulating support has to dynamically reproduce (stiffness and damping) the actual apparatus.

The severity and test method should be as described in clause 9.2.

9.4 *Test on the bushing alone*

If the size and/or complexity of the apparatus (transformer, GIS, building) does not allow the test to be performed as described in 9.2 or 9.3, the test should be performed on the bushing alone, rigidly connected to the shaker table. In this case the severity should be the RRS or the peak acceleration value at the flange of the bushing (see 6.2 and figure 4).

The sine-beat test method is recommended. In case the RRS at the flange is not available, coefficients K and R should be either obtained by calculation or taken from the values given in clauses 6 and 7.

10 Evaluation of the seismic qualification

10.1 *Combination of stresses*

The seismic stresses determined as described in clauses 7, 8 or 9 should be combined with other service stresses to evaluate the total stress induced by all the combined loads on the bushing.

The probability of an earthquake of the recommended seismic qualification level occurring during the lifetime of the bushing is low, as the maximum seismic load in a natural earthquake would only occur if the bushing were excited at its critical frequencies with maximum acceleration. As this would last only a few seconds, a combination of extreme electrical and environmental service loads would lead to unrealistic conservatism.

Consequently the following stresses are considered to occur simultaneously, if not otherwise specified (see IEC 1264):

- the stress of an operating load equal to 70 % of the cantilever operating load specified for the bushing;
- the stress of wind pressure of 70 Pa;
- the stress determined by the components of the mass of the bushing which acts perpendicular to the bushing axis;
- the stress of the average internal pressure at normal service conditions;
- the stress induced by the seismic event (clauses 7, 8 or 9).

These stresses can either be included in the test or analysis model, or separately added.

NOTES

1 This combination of stresses assumes that connection lines do not limit the motion of the terminal of the bushing during the seismic event.

2 This load combination is based on a reasonable conservatism that may not apply to each installation.

10.2 *Cantilever test*

A cantilever test allows the highest permissible stress of the bushing to be determined.

A cantilever test can be performed on a complete bushing or on parts of it. When testing a separate insulator, the clamping arrangement should be equal to that of the complete bushing. The test procedure should be in agreement with IEC 137.

10.3 *Acceptance criteria*

The bushing should insulate and carry current during and after the earthquake. No crack, leakage, permanent deflection or relative movement of parts is permitted.

The bushing is considered to be qualified for the seismic requirement if:

– the bending stress of the insulator resulting from the combination of stresses is not higher than the 100 % level of figure 1 and table 1 of IEC 1264;

– metallic parts are not stressed above the yielding point by the combined stresses. Assembly fittings, specially designed for seismic purpose (e.g. to reduce the natural frequency or increase the damping) may however use friction and ductility in a controlled way.

NOTE – By considering the actual stress-strain relationship and stress redistribution, the stress limit in metallic parts need not be satisfied at a specific location if the stress is a self-limiting secondary stress or if it is caused by a local structural discontinuity which affects a relatively small volume of material and does not have a significant effect on the overall stress or strain pattern.

11 Necessary exchange of information

11.1 *Information supplied by the apparatus manufacturer*

When specifying, the purchaser should provide as much of the following information as necessary, as well as any additional information needed to determine clearly the required characteristics.

a) *Severity*

It should be clearly stated if the severity is to be applied to the bushing flange or to the apparatus base. Severity at the bushing flange is recommended.

b) *Details of mounting*

Position and angle of mounting.

c) *Apparatus stiffness*

For qualification by calculation, the stiffness of the bushing support (e.g. angle of deflection vs bending moment) and the damping of the structure should be stated. If the stiffness of the support is so high that the natural frequency of the bushing can be expected to be above 9 Hz, it should also be stated that the rest of the structure down to the base is equally stiff, otherwise the lower accelerations at high frequencies may not be utilized.

d) *Dynamic analysis*

Qualification by dynamic analysis is to be made by the manufacturer of the apparatus (e.g. a transformer) because of the great amount of structural data required. The apparatus manufacturer requests the necessary data from the bushing manufacturer.

11.2 *Information supplied by the bushing manufacturer*

a) *Design data*

In case of dynamic analysis of the complete apparatus, the bushing manufacturer should provide:

- the geometrical parameters (i.e. dimensions, centre of gravity, moment of inertia) and masses of the complete bushing;
- the mechanical properties (i.e. Young and shear modulus, flexural/compressive/ tensile strength) of the porcelain and the damping ratio of the bushing, unless standard values can be used.

The apparatus manufacturer will perform the dynamic analysis and inform the bushing manufacturer of the results to be used in the evaluation according to clause 10.

b) *Seismic qualification report*

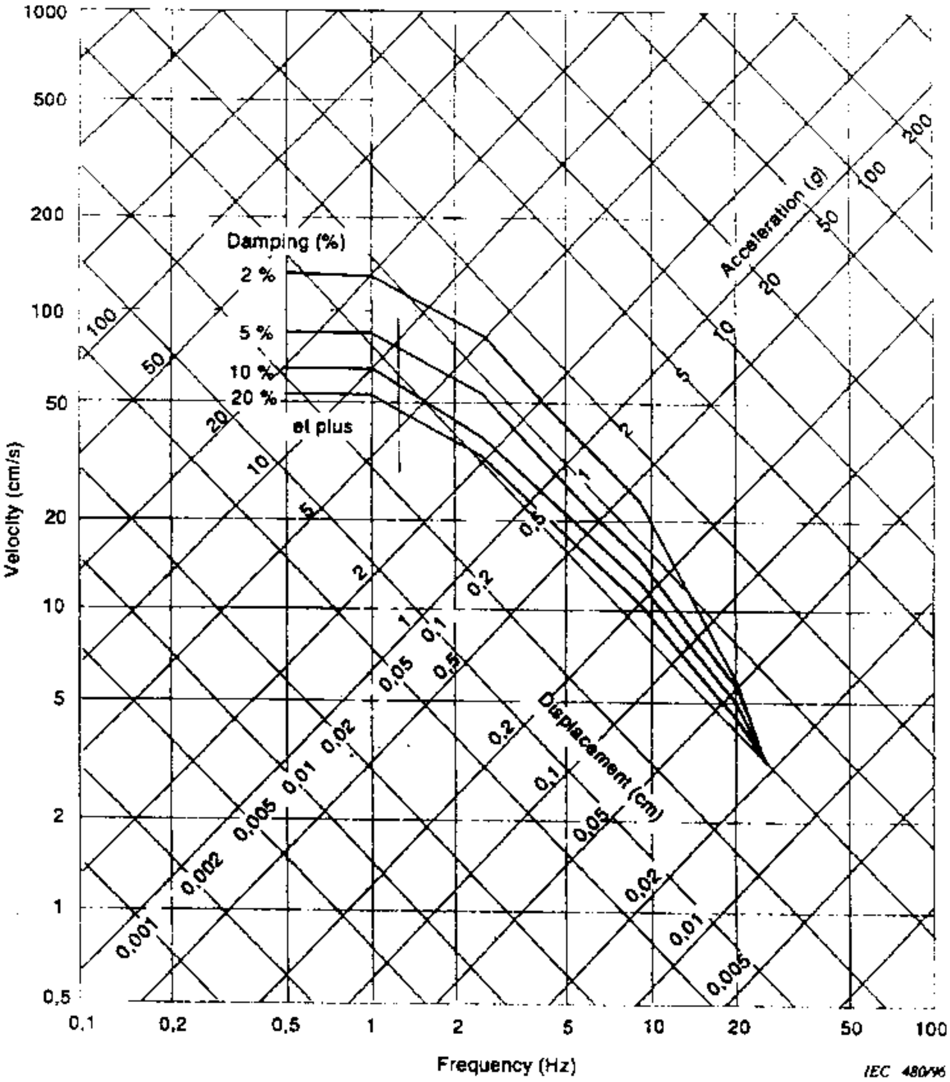
A report showing the result of the evaluation performed according to clause 10. The report should contain a description of the bushing, the assumptions adopted and the results obtained. In the report the maximum displacement of the bushing terminal during the earthquake should be provided.

c) *Test record*

If tests are performed, the report should contain identification of test object, test location, test equipment, description of the test, results (resonance frequencies and damping) and significant conclusions.

When qualification is performed according to 9.4, information should be given in order to justify that the adequacy of the bushing for a certain ground acceleration level is related to particular apparatus dynamic parameter.

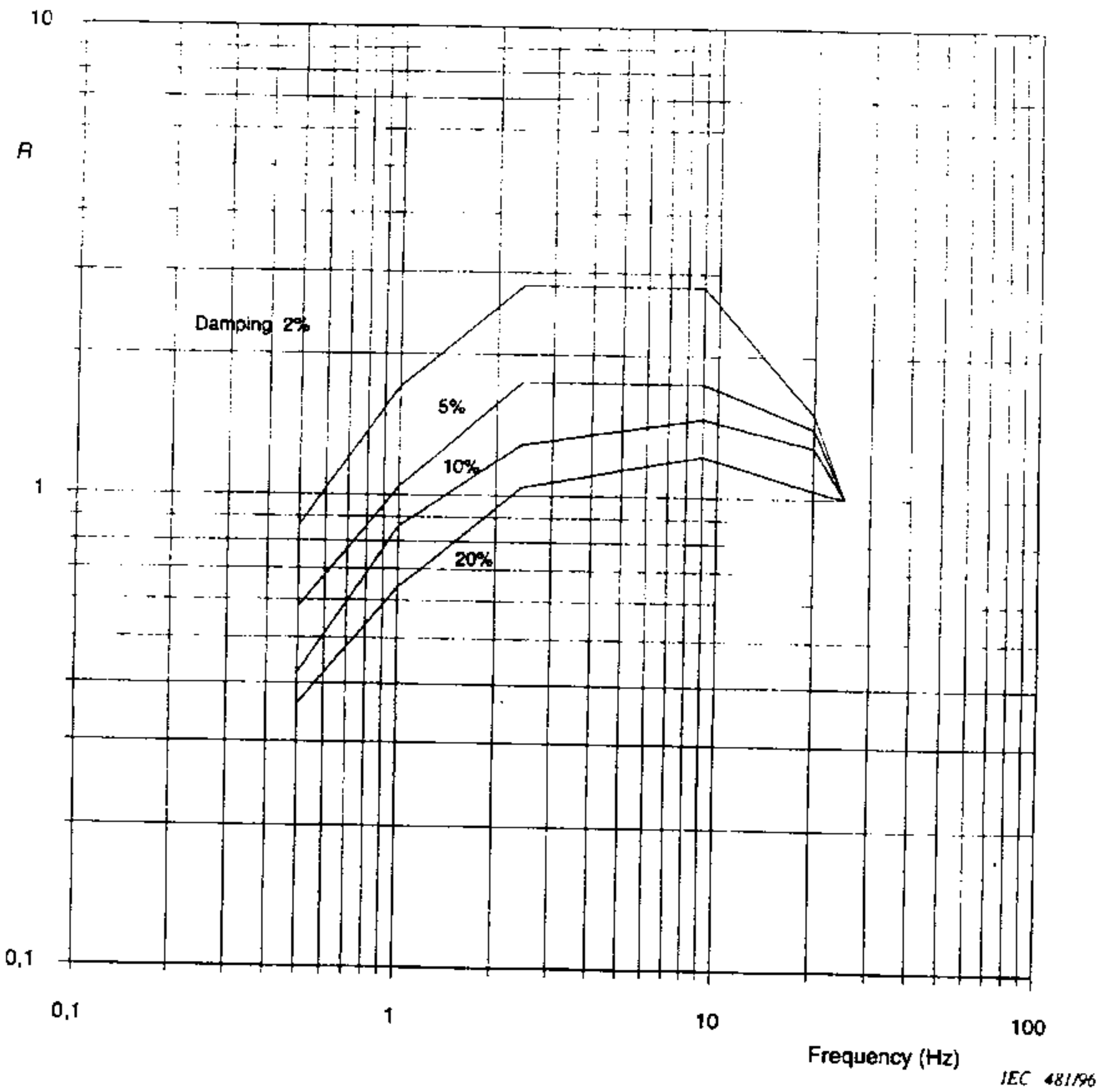
When reference is made to tests on apparatus similar to the actual, the following information should be given: description of both with details of their differences, test results and their extrapolation to the actual apparatus.



Frequency Hz	Response acceleration m/s²			
	Damping ratio 2 %	Damping ratio 5 %	Damping ratio 10 %	Damping ratio 20 % and more
0,5	4,3	2,9	2,1	1,8
1,0	8,5	5,2	4,3	3,2
2,4	14,0	8,7	6,4	5,2
9,0	14,0	8,7	7,3	6,1
20,0	7,5	7,0	6,4	5,2
25,0	5,0	5,0	5,0	5,0

NOTE – According to IEC 68-3-3, the value of g is rounded up to the nearest unit, that is 10 m/s².

Figure 1 – RRS for ground mounted equipment – Qualification level: AG5: ZPA = 5 m/s² (0,5 g)



Frequency Hz	Response factor *R*			
	Damping ratio 2 %	Damping ratio 5 %	Damping ratio 10 %	Damping ratio 20 % and more
0,5	0,86	0,58	0,42	0,36
1,0	1,70	1,04	0,86	0,64
2,4	2,80	1,74	1,28	1,04
9,0	2,80	1,74	1,46	1,22
20,0	1,50	1,40	1,28	1,04
25,0	1,00	1,00	1,00	1,00

Figure 2 – Response factor *R*

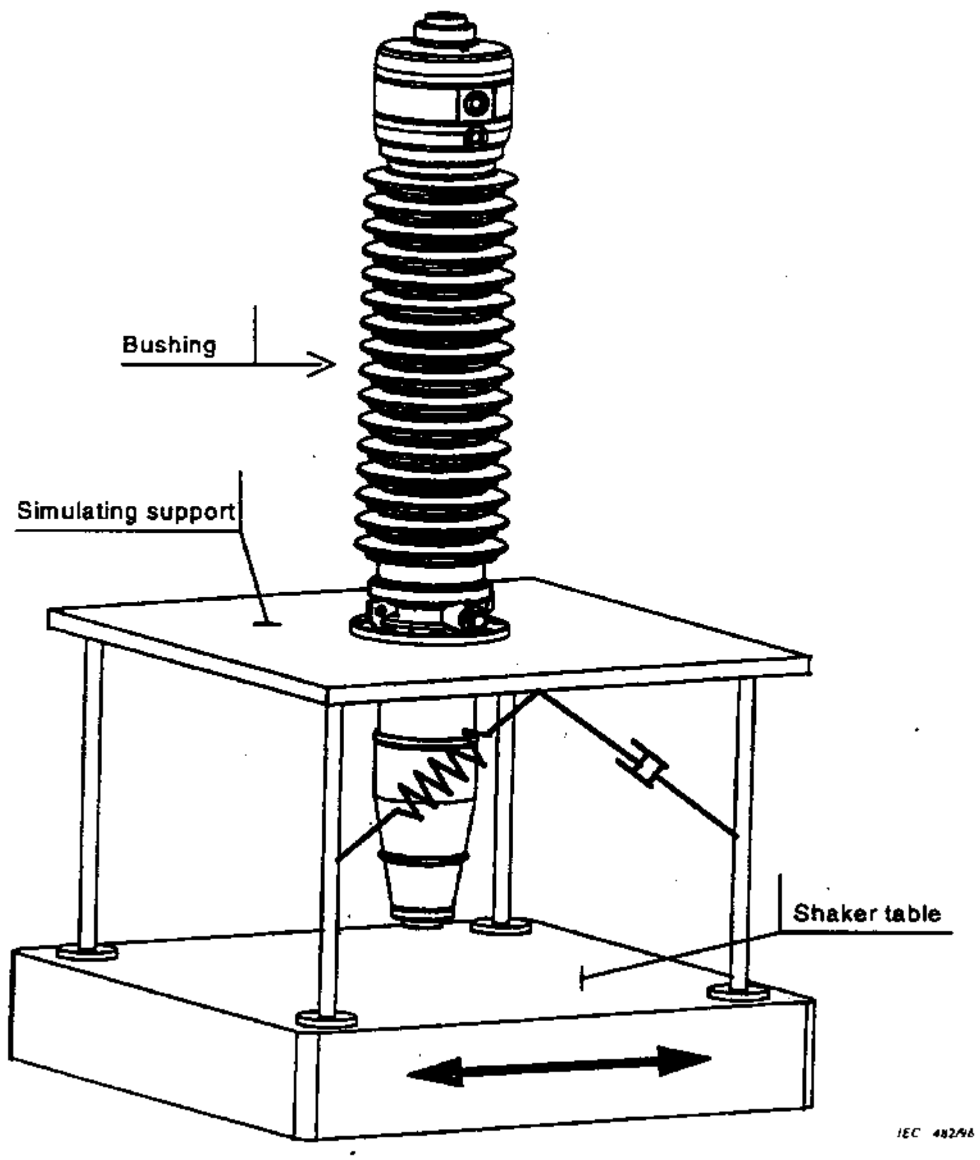
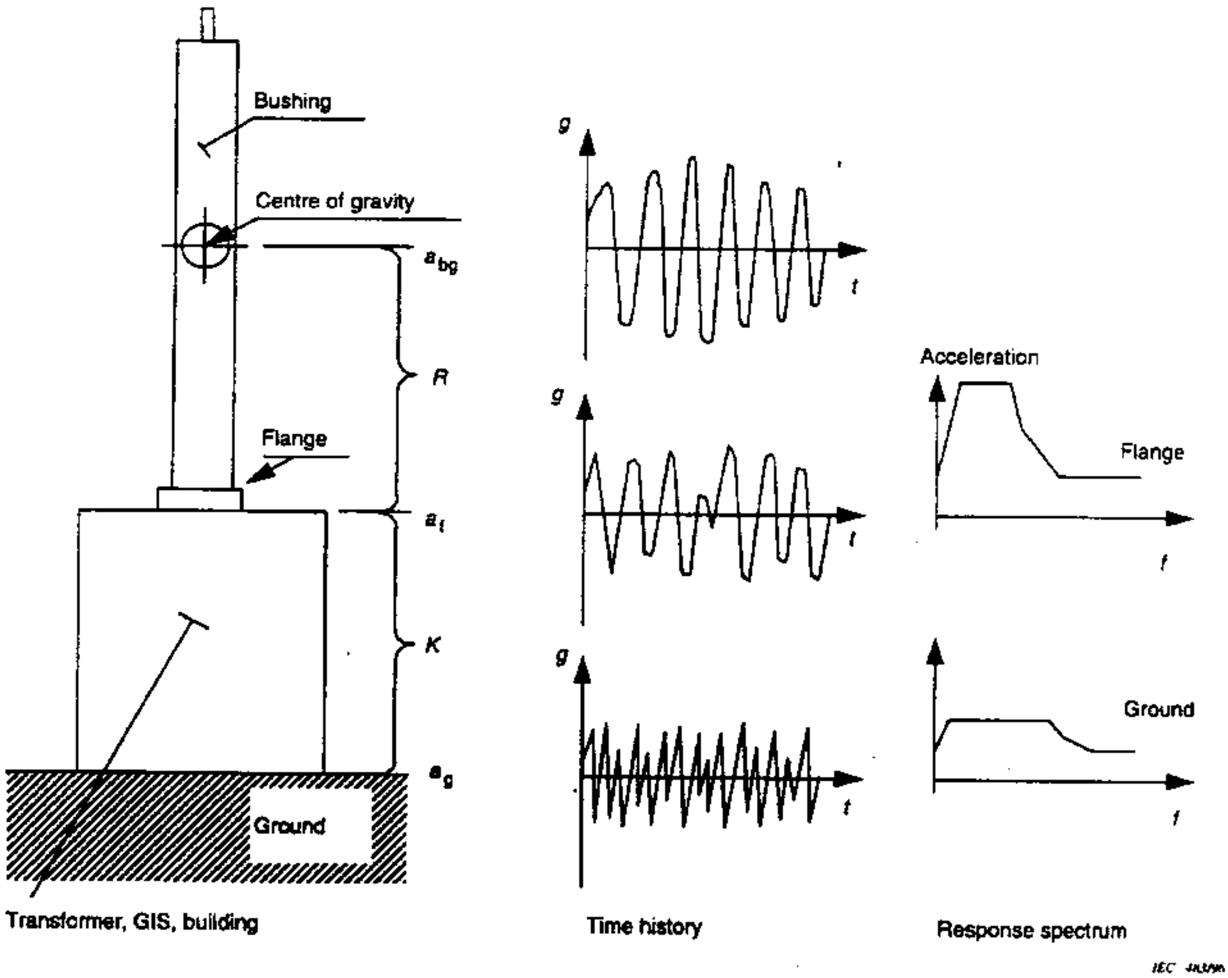


Figure 3 – Test with simulating support according to 9.3

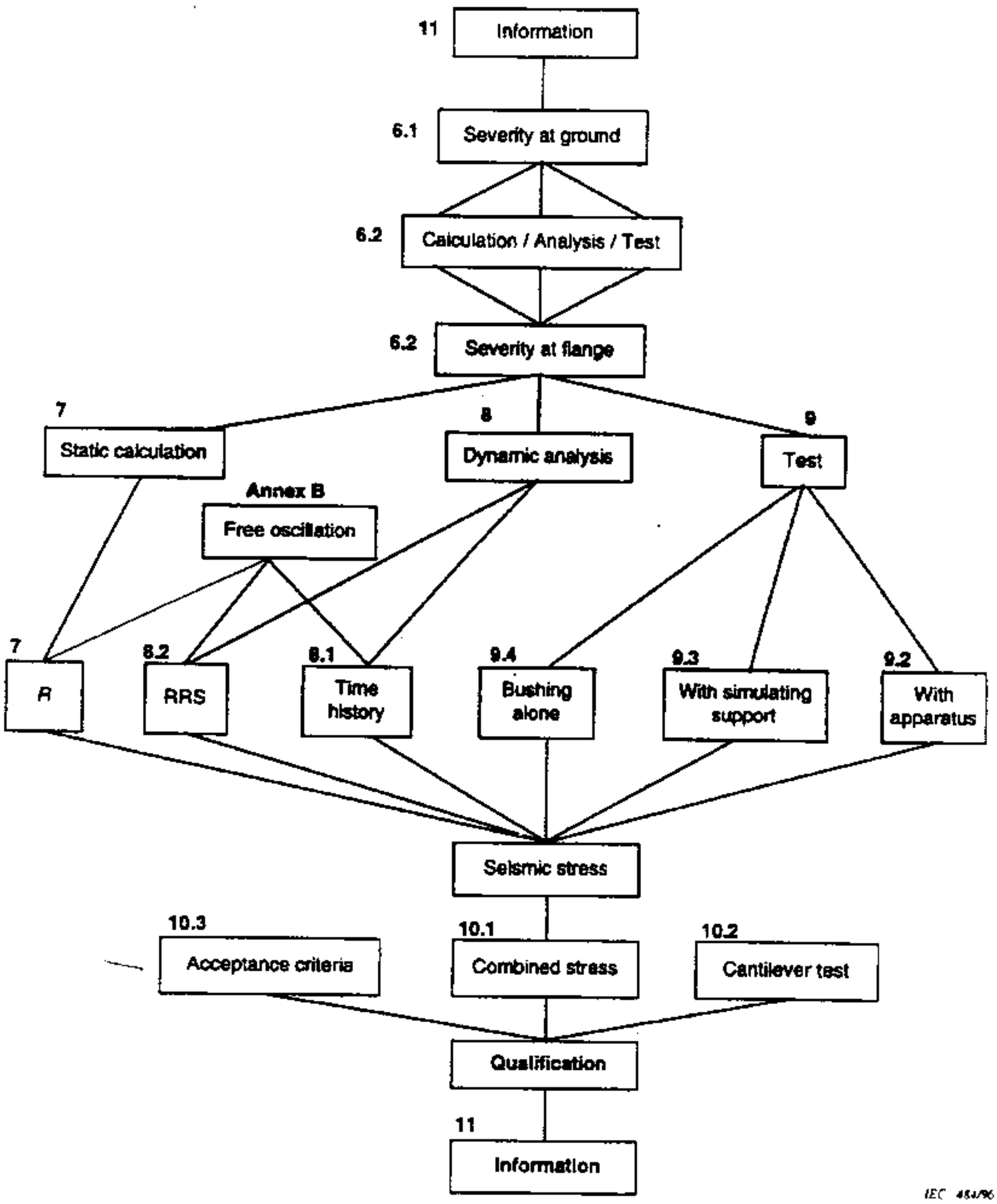


NOTE – Time histories and relevant response spectra are given as examples only.

Figure 4 – Determination of the severity

Annex A
(informative)

Flow chart for seismic qualification



NOTE – Numbers at the blocks refer to clauses and subclauses of this technical report.

Figure A.1 – Flow chart for seismic qualification

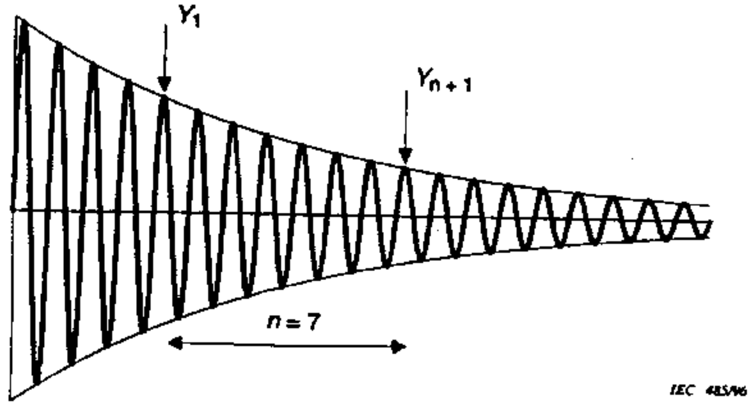
Annex B
(informative)

Free oscillation test

The natural frequency and damping can be obtained by a free oscillation test. Great care should be taken to distinguish between the data of the bushing and the data of the test frame. The test can be performed on the bushing when it is mounted upon the apparatus to obtain data for the actual application. Due to non-linear dynamic behaviour of the bushing, the test should preferably be performed with amplitude levels similar to those expected during an earthquake, in order to obtain correct values on both frequency and damping.

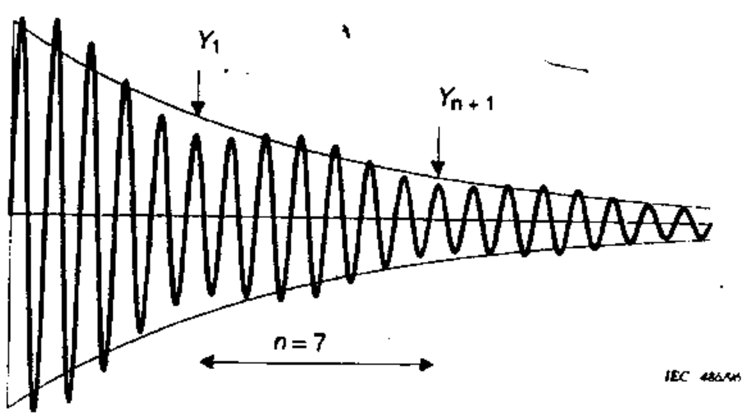
The bushing should be mounted as in service condition to the test frame or apparatus. A string should be connected to the terminal, pulled with a force corresponding to the expected earthquake stresses and then suddenly released.

Measurement transducers attached to the insulator and the bushing flange record the free oscillation of the bushing. If the flange also oscillates, this movement is subtracted if frequency and damping of the bushing itself are the sought values.



n represents the number of cycles.

Figure B.1 – Typical case of free oscillations



n represents the number of cycles.

Figure B.2 – Case of free oscillations with beats

The exponential curve in figure B.1 is the envelope of the peak values. The exponential curve in figure B.2 is obtained by using the least square roots of the peak values.

The damping ratio is calculated as follows:

$$\frac{1}{2\pi n} \times \ln \left(\frac{Y_n}{Y_{n+1}}\right) \times 100\%$$

The natural frequency and damping should be measured after a few periods, and before the amplitude has been significantly attenuated as shown in figures B.1 and B.2.

The method described is commonly used to measure natural frequency and damping. Other methods can also be used.

Annex C
(informative)

Oscillations at the centre of gravity

The vibration at the centre of gravity of the bushing is of importance for the qualification by static calculation (see clause 7).

As explained below, there is no simple relationship between the vibration occurring at the centre of gravity of the bushing during an earthquake and the equivalent acceleration a_{bg} used in clause 7. The value of a_{bg} is taken in order to obtain $M_s = a_{bg} \times d_p \times m_p$ that gives a bending moment at the critical cross-section equivalent to that occurring during an earthquake. The explanation of the relation $a_{bg} = a_f \times S_c \times R$ is given in the following clauses.

C.1 Effect of the first bending mode

It is assumed that the bushing is equivalent to a clamped free beam and that the seismic wave excites only the first bending mode. By computation of this model for the first bending mode, and for a seismic excitation, the following can be determined:

- the bending moment at the base;
- the acceleration of the centre of gravity of the bushing (a_{cg}).

Therefore: $a_{bg} = 1{,}67 \times a_{cg} = 0{,}89 \times R \times a_f$

This is commonly taken as: $a_{bg} = R \times a_f$

NOTE – $a_{cg} = 0{,}54 \times R \times a_f$

C.2 Determination of S_c

The coefficient S_c aims to take into account the effects of both multifrequency excitation and multimode response (see definition in clause 4).

In the case of a bushing, the first bending mode, and possibly the second bending mode, is excited. An increase in stress of 4,5 % maximum over that of the first bending mode, is obtained by the effect of the second bending mode. A value of S_c between 1,0 and 1,5 without any additional safety margin is recommended.

C.3 Value of a_{bg}

From the above:

$$a_{bg} = S_c \times a_f \times R = 1{,}5 \times a_f \times R$$

As explained above, a_{bg} is different from the acceleration at the centre of gravity due to the seismic excitation.

a_{bg} and a_{cg} differ from the value measured at the centre of gravity of the bushing excited on the shaker table with the RRS at the flange level. On the shaker table the absolute acceleration resulting from all modes is measured, sometimes with the effect of coupling axes. a_{bg} and a_{cg} represent a relative acceleration also called pseudo-acceleration. The relative acceleration comes from the seismic excitation as explained below.

Consider the following single degree of freedom system:

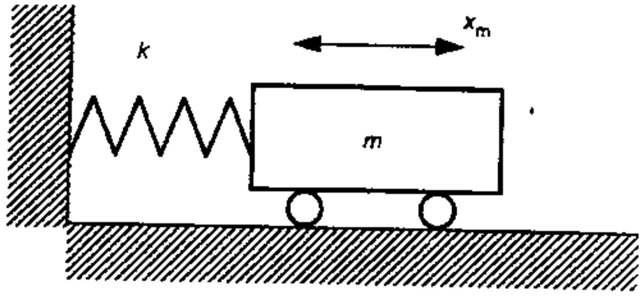


Figure C.1 – Single degree of freedom system

The equation of motion is:

$$m\ddot{X}_m + k(X_m - X_s) = 0$$

where

X_m is the absolute displacement of the mass;

$\ddot{X}_m$ is the absolute acceleration of the mass;

X_s is the absolute displacement of the base;

$\ddot{X}_s$ is the absolute acceleration of the base.

That gives: $m\ddot{X} + kX = -m\ddot{X}_s$

where

X is the relative displacement $(X_m - X_s)$;

$\ddot{X}$ is the relative acceleration $(\ddot{X}_m - \ddot{X}_s)$;

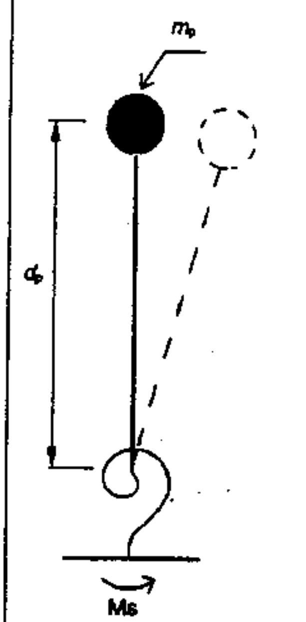
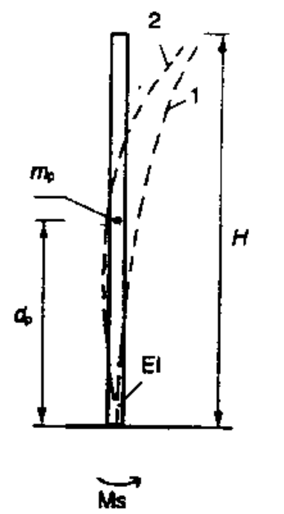
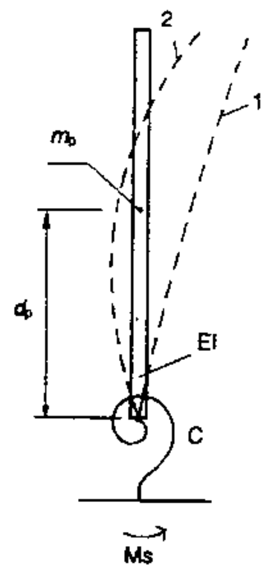
$-m\ddot{X}_s$ is the force acting on the system.

By computation, a value $\ddot{X}$ (termed a_{cg} in C.1) is obtained. Then a_{cg} represents the relative acceleration at the centre of gravity of the bushing.

The bending moment (and stress at the critical cross-section) is connected to the relative acceleration and not to the absolute acceleration. Commonly speaking, the term acceleration is used for relative acceleration.

C.4 Typical seismic response of cantilever type of structures

Table C.1 – Examples of typical seismic responses

Characteristic	Type of structure								
	Single mass (concentrated mass)			Bending deflection (clamped base)			Hinged elastic rod with angular spring (elastic base)		
Height (H) = 5,0 m d_p = 2,5 m Mass (m_p) = 1250 kg Bending stiffness (EI) = 32,8 MN/m² Damping ratio = 2 % Spring stiffness (C) = 4,3 MN · m/rad									
	Mode 1	Mode 2	SRSS	Mode 1	Mode 2	SRSS	Mode 1	Mode 2	SRSS
Natural frequency (HZ)	3,7	–	–	8,0	46,9	–	3,0	35,3	–
Response acceleration (m/s²)	14	–	–	14	5	–	14	5	–
a_{c0} (m/s²)	14	–	14	5,8	3,0	6,5	10,5	2,2	10,7
Acceleration of the tip (m/s²)	–	–	–	21,6	4,1	22,0	21,0	3,6	21,3
M_s (N · m)	43 750	–	43 750	39 135	1250	39 155	43 217	152	43 217
NOTE – Values of this table are obtained from a finite element analysis (Timoshenko type of beam).									

Many types of electrical apparatus may be considered as a cantilever type of structure only connected to foundation at base. Examples of such apparatus are bushings, measurement transformers and surge arresters. The seismic response of this type of structure can be predicted using well-known formulae for the dynamic behaviour of structures.

The elastic characteristics of apparatus will be inside a range given by the behaviour of an elastic beam deformed by bending and that of a hinged elastic rod with angular flexibility at base.

The seismic response is usually dominated by the lowest mode of structure (exceptions may be very flexible structures with lowest natural frequency below 1 Hz), especially since SRSS procedure (Square Root of the Sum of Squares) may be used for combining modal response to resultant design value.

To assess the bending moment (M_s) at the critical cross-section, the commonly used simplified procedure of applying a seismic acceleration (given by estimated natural frequency and damping of lowest mode) at the centre of gravity yields a good approximation. See examples of structures in table C.1.

The actual seismic acceleration at the middle of the structure is, however, not equal to the acceleration of the response spectrum but lower, typically in the range 0,5 to 0,8 of that acceleration level, depending on the shape of the lowest eigenmode. For the acceleration at the tip of the structure, a value of 1,6 times the response acceleration is appropriate.

Annex D
(informative)

Qualification by static calculation – Example on transformer bushing

D.1 Seismic ground motion

In all calculations of earthquakes affecting bushings, the vertical acceleration shall be applied downwards in the direction of the acceleration due to gravity. This gives the greatest load on the bushing:

- horizontal ground acceleration, a_{gh}, (ZPA): 5 m/s²
- vertical ground acceleration; a_{gv}: 2,5 m/s²

D.2 Critical part of the bushing

When a cantilever test is performed or during an earthquake, the most critical part of the bushing is at the insulator base. The two major critical factors are the risk of oil leakage (see figure D.1) and the bending stress at the insulator base. For this reason the bending moments are calculated at the insulator base.

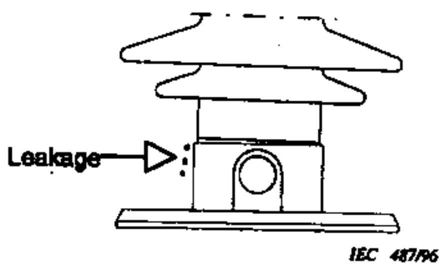


Figure D.1 – Critical part of the bushing

D.3 Static calculation

The transformer tank is very heavy compared to the bushings, but finite-element (FEM) analysis shows that the transformer tank cannot be considered as rigid. The ground acceleration is amplified through the transformer tank to the transformer tank cover with an amplification factor *K*. Without background information, the amplification factor *K* is assumed to be 1,5 (see 6.2). If the bushing is mounted on a turret this can be considered rigid. Therefore the transformer tank cover and the turret are subjected to the same acceleration:

- horizontal acceleration at the transformer tank cover/turret ($K \times a_{gh} = K \times$ ZPA): 7,5 m/s²
- vertical acceleration at the transformer tank cover/turret ($K \times a_{gv}$): 3,75m/s²

The acceleration of the transformer tank cover will be amplified to the bushing with the response factor *R*. The response factor depends on the natural frequency and the damping of the bushing mounted on the transformer tank cover. The value of the response factor *R* is taken from figure 2.

If the response factor R cannot be estimated, the conservative value of the response factor at a certain value of damping is used. For a bushing mounted on a transformer tank cover a damping ratio of 5 % can be assumed:

- natural frequency for bushing mounted on the transformer tank cover (Hz): unknown
- damping ratio for bushing mounted on the transformer tank cover: 5 %
- response factor R, taken from figure 2 (conservative value): 1,74

The response is then multiplied by a coefficient, S_c, which takes into account both multifrequency excitation and multimode response. The conservative value of the coefficient is 1,5.

The acceleration of the transformer tank cover, the response factor of the bushing mounted on the transformer tank cover, the static coefficient and the air side mass, m_p, of the bushing give rise to a force that affects the bushing at the air side centre of gravity (see D.3.1). If the bushing is mounted at angles to the vertical plane, both the vertical and the horizontal parts of the earthquake will affect the bushing.

D.3.1 *Seismic load*

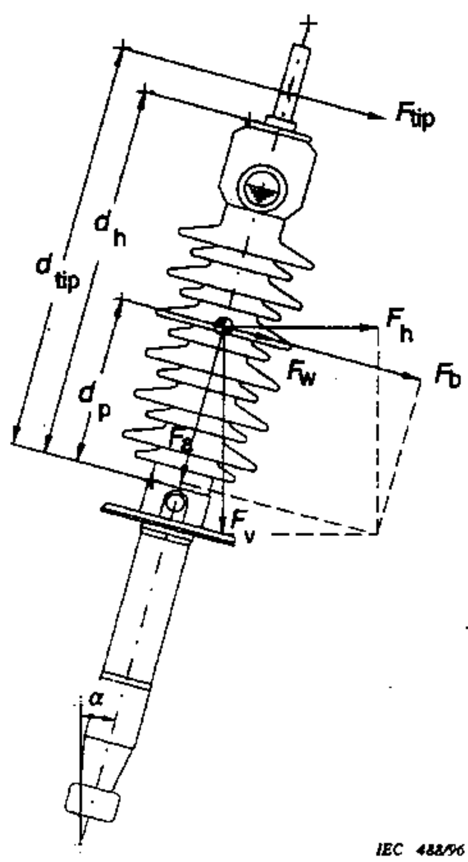


Figure D.2 – Forces affecting the bushing

In these seismic calculations the vertical acceleration is applied downwards, in the same direction as the acceleration due to gravity. This produces the greatest load on the bushing.

The air side mass of the bushing, m_p, is the mass of all the parts of the bushing above the bushing flange.

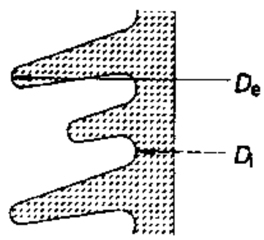
d_p is the distance from the critical part of the bushing flange to the air side centre of gravity (see figure D.2):

– air side mass, m_p:		63 kg
– d_p:		590 mm
– mounting angle to the vertical plane, α:		20°
– horizontal force, F_h,	$(m_p \times K \times a_{gh} \times R \times S_c)$:	1233 N
– vertical force, F_v,	$(m_p \times K \times a_{gv} \times R \times S_c + m_p \times g)$:	1247 N
– compressive force, F_a,	$(-F_h \times \sin\alpha + F_v \times \cos\alpha)$:	750 N
– bending force, F_b,	$(F_h \times \cos\alpha + F_v \times \sin\alpha)$:	1585 N
– bending moment due to the seismic event and gravity, M_{bs},	$(F_b \times d_p)$:	0,94 kN · m

D.3.2 *Wind load*

Wind loads are considered as static loads. As a combination of the extreme values of all electrical and environmental service loads would lead to unrealistic conservatism, a wind pressure of 70 Pa acting at the same time as an earthquake should be assumed.

The resulting wind force (F_w) affects the bushing in its air side centre of gravity (see figure D.2):



IEC 489/96

Figure D.3 – Porcelain diameters

– wind pressure, p:		70 Pa
– outer diameter of the porcelain sheds, D_e, see figure D.3:		280 mm
– outer diameter of the porcelain core, D_i, see figure D.3:		150 mm
– distance from the critical cross-section to the top of the bushing, d_h, see figure D.2:		1205 mm
– wind force, F_w, see figure D.2,	$(p \times (D_e + D_i)/2 \times d_h)$:	18,14 N
– bending moment due to the wind, M_{bw},	$(F_w \times d_p)$:	0,01 kN · m

D.3.3 *Terminal load*

The tip load at an earthquake event is equal to 70 % of the cantilever operating load specified for the bushing according to 10.1:

- cantilever operating load, taken from IEC 137 (U_r = 170 kV, I_r = 800 A, Classe 1), F_{op}: 625 N
- tip load at the terminal, F_{tip}, see figure D.2, ($F_{op} \times 0,7$): 438 N
- distance from the critical cross-section to the terminal, d_{tip}, see figure D.2: 1 325 mm
- bending moment due to the tip load, M_{btip}, ($F_{tip} \times d_{tip}$): 0,58 kN · m

D.4 Guaranteed bending strength

The bushing must withstand a cantilever test load in accordance with IEC 137 without leakage or damage. The bending moment occurring during this test should be compared with the total bending moment occurring at the critical cross-section due to the seismic, wind, terminal loads and the effect of gravity:

- cantilever withstand load, F_{test}: 1250 N
- bending moment occurring under cantilever test: ($F_{test} \times d_{tip}$) 1,66 kN · m
- total bending moment occurring during the seismic event:(M_{bs} + M_{bw} + M_{btip}) 1,53 kN · m

Result of qualification:

The bending strength is greater than the stress during the specified seismic event. The bushing is therefore qualified.

1.
Numéro de la Norme CEI:

....

2.
Pourquoi possédez-vous cette norme? (plusieurs réponses possibles). Je suis:

- ☐ l'acheteur
- ☐ l'utilisateur
- ☐ bibliothécaire
- ☐ chercheur
- ☐ ingénieur
- ☐ expert en sécurité
- ☐ chargé d'effectuer des essais
- ☐ fonctionnaire d'Etat
- ☐ dans l'industrie
- ☐ autres..................

3.
Où avez-vous acheté cette norme?

....

4.
Comment cette norme sera-t-elle utilisée? (plusieurs réponses possibles)

- ☐ comme référence
- ☐ dans une bibliothèque de normes
- ☐ pour développer un produit nouveau
- ☐ pour rédiger des spécifications
- ☐ pour utilisation dans une soumission
- ☐ à des fins éducatives
- ☐ pour un procès
- ☐ pour une évaluation de la qualité
- ☐ pour la certification
- ☐ à titre d'information générale
- ☐ pour une étude de conception
- ☐ pour effectuer des essais
- ☐ autres..................

5.
Cette norme est-elle appelée à être utilisée conjointement avec d'autres normes? Lesquelles? (plusieurs réponses possibles):

- ☐ CEI
- ☐ ISO
- ☐ internes à votre société
- ☐ autre (publiée par..........)
- ☐ autre (publiée par..........)
- ☐ autre (publiée par..........)

6.
Cette norme répond-elle à vos besoins?

- ☐ pas du tout
- ☐ à peu près
- ☐ asez bien
- ☐ parfaitement

7.
Nous vous demandons maintenant de donner une note à chacun des critères ci-dessous (1, mauvais; 2, en-dessous de la moyenne; 3, moyen; 4, au-dessus de la moyenne; 5, exceptionnel; 0, sans objet)

- ☐ clarté de la rédaction
- ☐ logique de la disposition
- ☐ tableaux informatifs
- ☐ illustrations
- ☐ informations techniques

8.
J'aimerais savoir comment je peux reproduire légalement cette norme pour:

- ☐ usage interne
- ☐ des renseignements commerciaux
- ☐ des démonstrations de produit
- ☐ autres ....

9.
Quel support votre société utilise-t-elle pour garder la plupart des ses normes?

- ☐ papier
- ☐ microfilm/microfiche
- ☐ bandes magnétiques
- ☐ CD-ROM
- ☐ disquettes
- ☐ abonnement à un serveur électronique

9A.
Si votre société conserve en totalité ou en partie sa collection de normes sous forme électronique, indiquer la ou les formats:

- ☐ format tramé (ou image balayée ligne par ligne)
- ☐ texte intégral

10.
Sur quels supports votre société prévoit-elle de conserver sa collection de normes à l'avenir (plusieurs réponses possibles):

- ☐ papier
- ☐ microfilm/microfiche
- ☐ bande magnétique
- ☐ CD-ROM
- ☐ disquette
- ☐ abonnement à un serveur électronique

10A.
Quel format serait retenu pour un moyen électronique? (une seule réponse)

- ☐ format tramé
- ☐ texte intégral

11.
A quel secteur d'activité appartient votre société? (par ex. ingénierie, fabrication)

....

12.
Votre société possède-t-elle une bibliothèque de normes?

- ☐ Oui
- ☐ Non

13.
En combien de volumes dans le cas affirmatif ?

....

14.
Quelles organisations de normalisation ont publiées les normes de cette bibliothèque ? (ISO, DIN, ANSI, BSI, etc.):

....

15.
Ma société apporte sa contribution à l'élaboration des normes par les moyens suivants (plusieurs réponses possibles):

- ☐ en achetant des normes
- ☐ en utilisant des normes
- ☐ en qualité de membre d'organisations de normalisation
- ☐ en qualité de membre de comités de normalisation
- ☐ autres ....

16.
Ma société utilise: (une seule réponse)

- ☐ des normes en français seulement
- ☐ des normes en anglais seulement
- ☐ des normes bilingues anglais/français

17.
Autres observations:

....
....
....
....
....

18.
Pourriez-vous nous donner quelques informations sur vous-même et votre société?:

nom: ....

fonction:......................

nom de la société:..............

adresse:......................

....

....

....

nombre d'employés:..............

chiffre d'affaires:..............

1.
No. of IEC standard:

....

2.
Tell us why you have the standard. (check as many as apply). I am:

- ☐ the buyer
- ☐ the user
- ☐ a librarian
- ☐ a researcher
- ☐ an engineer
- ☐ a safety expert
- ☐ involved in testing
- ☐ with a government agency
- ☐ in industry
- ☐ other ....

3.
This standard was purchased from:

....

4.
This standard will be used (check as many as apply):

- ☐ for reference
- ☐ in a standards library
- ☐ to develop a new product
- ☐ to write specifications
- ☐ to use in a tender
- ☐ for educational purposes
- ☐ for a lawsuit
- ☐ for quality assessment
- ☐ for certification
- ☐ for general information
- ☐ for design purposes
- ☐ for testing
- ☐ other ....

5.
This standard will be used in conjunction with (check as many as apply):

- ☐ IEC
- ☐ ISO
- ☐ corporate
- ☐ other (published by ....)
- ☐ other (published by ....)
- ☐ other (published by ....)

6.
This standard meets my needs (check one):

- ☐ not at all
- ☐ almost
- ☐ fairly well
- ☐ exactly

7.
Please rate the standard in the following areas as (1) bad, (2) below average, (3) average, (4) above average, (5) exceptional (0) not applicable:

- ☐ clearly written
- ☐ logically arranged
- ☐ information given by tables
- ☐ illustrations
- ☐ technical information

8.
I would like to know how I can legally reproduce this standard for:

- ☐ internal use
- ☐ sales information
- ☐ product demonstration
- ☐ other ....

9.
In what medium of standard does your organization maintain most of its standards (check one):

- ☐ paper
- ☐ microfilm/microfiche
- ☐ mag tape
- ☐ CD ROM
- ☐ floppy disk
- ☐ on line

9A.
If your organization currently maintains part or all of its standards collection in electronic media please indicate the format(s).

- ☐ raster image
- ☐ full text

10.
In what medium does your organization intend to maintain its standards collection in the future (check all that apply):

- ☐ paper
- ☐ microfilm/microfiche
- ☐ mag tape
- ☐ CD ROM
- ☐ floppy disk
- ☐ on line

10A.
For electronic media which format will be chosen (check one):

- ☐ raster image
- ☐ full text

11.
My organization is in the following sector (e.g. engineering, manufacturing)

....

12.
Does your organization have a standards library:

- ☐ Yes
- ☐ No

13.
If you said yes to 12 then how many volumes:

....

14.
Which standards organizations published the standards in your library (e.g. ISO, DIN, ANSI, BSI, etc.):

....

15.
My organization supports the standards-making process by (check as many as apply):

- ☐ buying standards
- ☐ using standards
- ☐ membership in standards organizations
- ☐ serving on standards development committees
- ☐ other ....

16.
My organization uses (check one):

- ☐ French text only
- ☐ English text only
- ☐ Both English/French text

17.
Other comments:

....

....

....

....

....

18.
Please give us information about you and your company

name: ....

job title: ....

company: ....

address: ....

....

....

....

No. employees at your location: ....

turnover/sales: ....

Publications de la CEI préparées par le Comité d'Etudes n° 36 *(suite)*

720 (1981) Caractéristiques des isolateurs rigides à socle.

797 (1984) Résistance résiduelle des éléments de chaîne d'isolateurs en verre ou en matière céramique pour lignes aériennes après détérioration mécanique du diélectrique.

815 (1986) Guide pour le choix des isolateurs sous pollution

1109 (1992) Isolateurs composites destinés aux lignes aériennes à courant alternatif de tension nominale supérieure à 1 000 V – Définitions, méthodes d'essai et critères d'acceptation.
Amendement 1 (1995).

1211 (1994) Isolateurs en matière céramique ou en verre destinés aux lignes aériennes de tension nominale supérieure à 1 000 V – Essais de perforation.

1245 (1993) Essais de pollution artificielle sur isolateurs haute tension destinés aux réseaux à courant continu.

1264 (1994) Enveloppes isolantes sous pression en matière céramique pour l'appareillage à haute tension.

1325 (1995) Isolateurs pour lignes aériennes de tension nominale supérieure à 1 000 V – Eléments d'isolateurs en céramique ou en verre pour systèmes à courant continu – Définitions, méthodes d'essai et critères d'acceptation.

1463 (1996) Traversées – Qualification sismique.

IEC publications prepared by Technical Committee No. 36 *(continued)*

720 (1981)[1] Characteristics of line post insulators.

797 (1984) Residual strength of string insulator units of glass or ceramic material for overhead lines after mechanical damage of the dielectric.

815 (1986) Guide for the selection of insulators in respect of polluted conditions.

1109 (1992) Composite insulators for a.c. overhead lines with a nominal voltage greater than 1 000 V – Definitions, test methods and acceptance criteria.
Amendment 1 (1995).

1211 (1994) Insulators of ceramic material or glass for overhead lines with a nominal voltage greater than 1 000 V – Puncture testing.

1245 (1993) Artificial pollution tests on high-voltage insulators to be used on d.c. systems.

1264 (1994) Ceramic pressurized hollow insulators for high-voltage switchgear and controlgear.

1325 (1995) Insulators for overhead lines with a nominal voltage above 1 000 V – Ceramic or glass insulator units for d.c. systems – Definitions, test methods and acceptance criteria.

1463 (1996) Bushings – Seismic qualification.

Publication 1463

ICS 29.080.20

Typeset and printed by the IEC Central Office
GENEVA, SWITZERLAND