Seismic calculations on ABB bushings mounted on a transformer tank cover

Product information
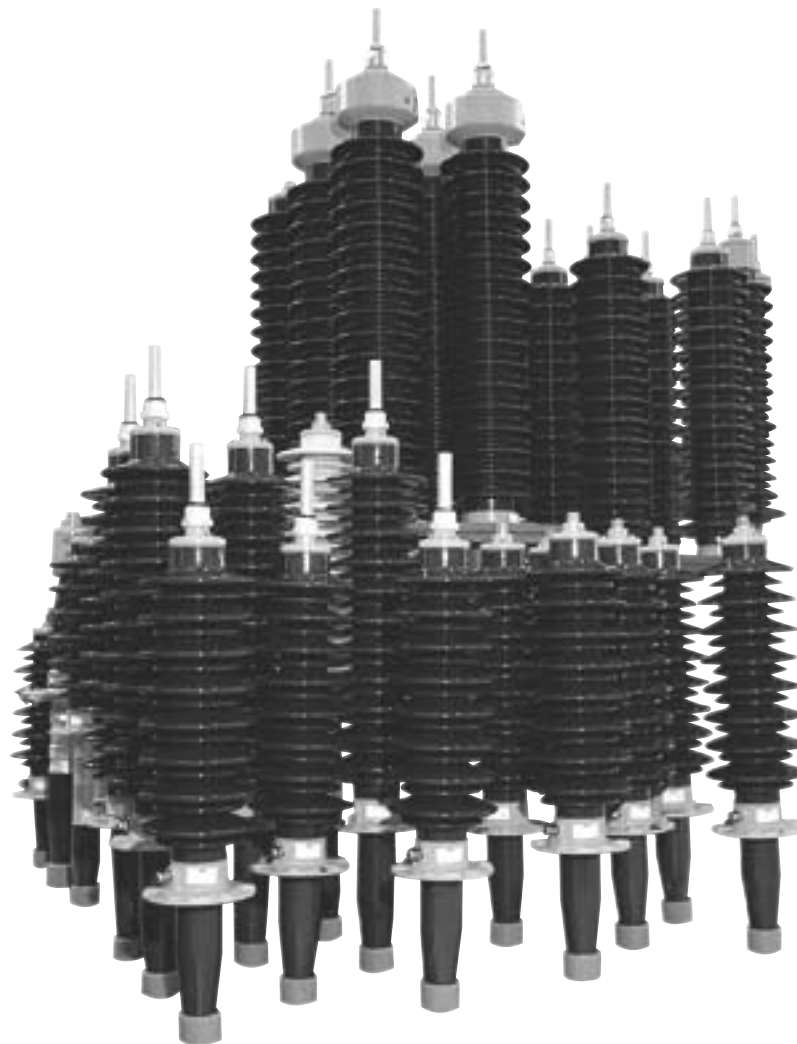
ABB

Safety information

Keep this instruction available to those responsible for the installation, maintenance, and operation of the bushing.

The installation, operation, and maintenance of a bushing present numerous potential unsafe conditions, including, but not limited to, the following:

■ High pressures

■ Lethal voltages

■ Moving machinery

■ Heavy components

■ Slip, stumble or fall

Specialized procedures and instructions are required and must be adhered to when working on such apparatus. Failure to follow the instructions could result in severe personal injury, death, and/or product or property damage.

Additionally, all applicable safety procedures such as regional or local safety rules and regulations, safe working practices, and good judgement must be used by the personnel when installing, operating, maintaining and/or disposing such equipment.

Safety, as defined in this instruction, involves two conditions:

1. Personal injury or death.

2. Product or property damage (includes damage to the bushing or other property, and reduced bushing life).

Safety notations are intended to alert personnel of possible personal injury, death or property damage. They have been inserted in the instructional text prior to the step in which the condition is cited.

The safety conditions are headed by one of the three hazard intensity levels which are defined as follows:

DANGER

Immediate hazard which will result in severe personal injury, death, or property damage.

WARNING

Hazard or unsafe practice which could result in severe personal injury, death, or property damage.

CAUTION: Hazard or unsafe practice which could result in minor personal injury, or property damage.

Contents

1 General

The stable supply of electricity is an increasing social need in industrialised countries. If facilities are damaged by an earthquake, the supply of power is stopped for a considerable period of time, and it will have a disastrous influence over the social acitivities in the area. Therefore, seismic resistance of electrical equipment is of major concern with respect to ensure operation of electric power systems during and after even a very severe earthquake. ABB has long experience of delivering bushings satsifying rigorous seismic requirements all over the world (New Zealand, California, Chile, etc.).

2 Seismic ground motion

It has long been recognised that earthquakes are not evenly distributed over the earth, see Fig. 1. The eventual correlation of the earthquake pattern with the earth's major surface features, below the oceans as well as on land, was a fundamental key to the evolution of the plate tectonics concept which revolutionised earth science in the 1970s. The earth's surface plates move relatively each other and stresses are built up in the rocks. Rock is elastic and can, up to a point, accumulate strain where adjacent areas of rock are subjected to forces pushing or pulling them. Sometimes, for reasons that are not understood, seismic energy is released slowly and the rocks slide past each other. At other times, the seismic energy is released violently over a period of seconds as the rock ruptures, producing an earthquake.
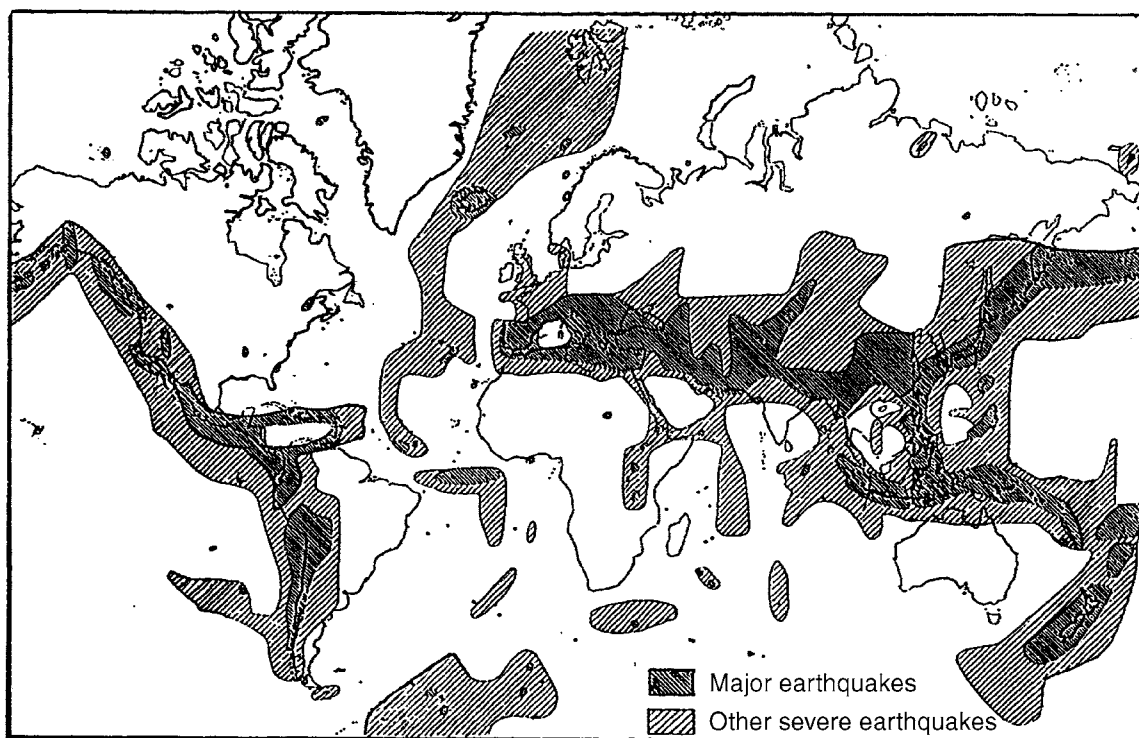

Fig. 1. Global approximate general map of the risk of earthquakes. More closely oblique lines correspond to expected major earthquake, ZPA = peak acceleration = 0.5 - 0.3 g (= 5-3 m/s²). Sparely oblique lines correspond to expected moderate earthquake, ZPA = about 0.2 g (= 2 m/s²). Observe that considerable local variations within an area occur.

For engineering design purposes the best information has been obtained from strong motion records of acceleration relatively near epicentre of the earthquake. For a major earthquake the peak acceleration (ZPA, Zero Period Acceleration) is 0.5-0.3 g (=3-5 m/s^2) and for a moderate one about 0.2 g (= 2 m/s^2), see Fig. 1. Other well-known measures of an earthquake magnitude like Richter magnitude and Intensity scales are not well suited for design puposes and there is no connection capable of being used between the Richter scale or the Intensity scale and the peak acceleration of an earthquake.

According to a study in Japan the ratio between the vertical and the horizontal component for most of the strong earthquakes is below 0.5, this ratio is also prescribed by IEC. The horizontal and the vertical components in earthquake waves are not necessarily in phase and the superposition of the two components is not simple in strict sense. However, if the bending moments due to the accelerations in horizontal and in vertical directions are added to each other, the solution is not on the pessimistic side. In all calculations of earthquakes affecting bushings apply the vertical acceleration downwards, in the same direction as the acceleration due to gravity. This produces the greatest load on the bushing.

3   How the earthquake affects the bushing

3.1   Mechanical design

The loads generates the greatest stress at the bottom of the flange. When a cantilever test is performed on the bushing or when an earthquake is affecting the bushing it is critical at the insulator base. The two major critical factors of the bushing at the insulator base is the risk of oil leakage, see Fig. 2, and the bending strength of the insulator at base. Therefore, we calculated forces, stresses, and moments at the insulator base.
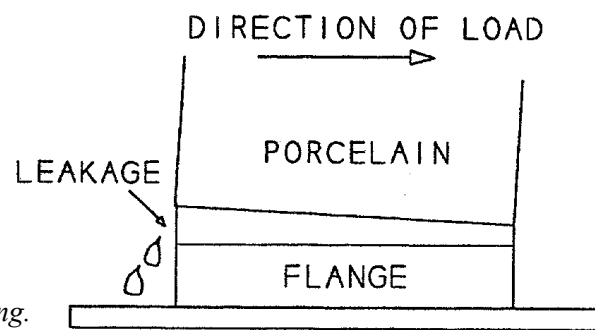
Fig. 2. The critical part of the bushing.

3.2   Static coefficient analysis

This method is normally adopted for rigid equipment, but it may also be used for flexible equipment, as a method which allows a simpler technique in return for added conservatism (IEC 61463).

The bushings are mounted on a transformer tank cover. The transformer tank is very heavy relatively the bushings but it is shown in FEM analysis that the transformer tank can not be considered as stiff. The ground acceleration is amplified through the transformer tank to the transformer tank cover with the superelevation factor, K, see Fig. 4. The super-elevation factor, K, is prescribed by IEC 61463 to 1.5. If the bushing

is mounted on a turret, one can consider the turret as stiff, which means that the transformer tank cover and the turret get the same acceleration, see Fig. 4.

A useful analytical procedure for assessment of the seismic load of the bushing mounted on a transformer tank cover is the Response Spectrum Method. The acceleration of the transformer tank cover is amplified to the bushing with an amplification factor equal to the response factor, R. The response factor, R, is taken from an RRS-diagram, see Table 1, and depends on the natural frequency and the damping for the bushing mounted on the transformer tank cover.

If it is not proven that the natural frequency of the bushing mounted on transformer tank cover is outside the range 2.4 - 9 Hz, the response, R, of the bushing mounted on the transformer tank cover is assumed to be the peak of the required response spectrum at a certain value of damping, see Table 1, (i.e. the response factor, R, is set to the conservative value at a certain value of damping if one does not know the natural frequency of the mounted bushing).

Values of damping can not normally be calculated, they have to be tested or estimated from tests on similar structures. For bushing mounted on transformer tank a damping value of 5 % may be used without further justification.

Table 1. Response factor for 5 % damping, taken from an RRS-diagram.

Natural frequency (Hz)	Response factor, R
0.5	0.58
0.6	0.67
0.7	0.76
0.8	0.86
0.9	0.95
1.0	1.04
1.2	1.14
1.4	1.24
1.6	1.34
1.8	1.44
2.0	1.54
2.2	1.64
2.4 - 9	1.74 = conservative value
10	1.71
12	1.65
14	1.59
16	1.52
18	1.46
20	1.40
22	1.24
25 - ∞	1.0

This response is then multiplied by a static coefficient, S_C, which has been stablished from experience to take into account the effects of both multifrequency excitation and multimode response. The value of S_C depends on the natural frequency of the mounted bushing.

Natural frequency, fn $\leq$ 9 Hz $S_C = 1.5$

9 < natural frequency, fn < 25 Hz $S_C = 1 + 0.5 \cdot \dfrac{25\text{-}fn}{25\text{-}9}$

Natural frequency, fn $\geq$ 25 Hz $S_C = 1.0$
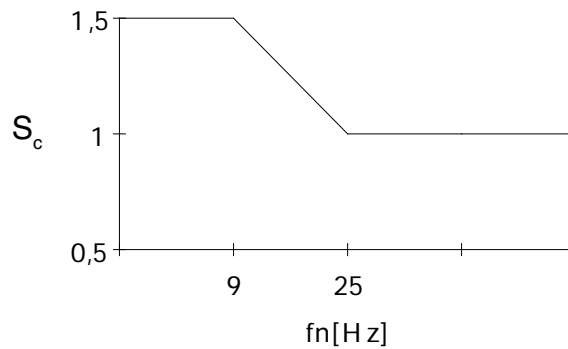
Fig. 3. The static coefficient at various natural frequences.

If the natural frequency is not known the conservative value of the static coefficient, $S_C = 1.5$, shall be used.

Fig. 4. Static coefficient analysis of the transformer.

Variables:

a_{HG} = Horizontal ground acceleration = Zero period acceleration (ZPA)

a_{VG} = Vertical ground acceleration = ZPA/2

a_{HC} = Horizontal transformer tank cover acceleration

a_{VC} = Vertical transformer tank cover acceleration

a_{HT} = Horizontal turret acceleration

a_{VT} = Vertical turret acceleration

F_{eq} = Force on the bushing due to the earthquake

Fundamental relationships

The earthquake is amplified through the transformer tank:

$$a_{HC} = K \cdot ZPA$$

$$a_{VC} = K \cdot a_{VG} = K \cdot ZPA \cdot \tfrac{1}{2}$$

We asssume that the turret is stiff, gives:

$$a_{HT} = a_{HC} = K \cdot ZPA$$

$$a_{VT} = a_{VC} = K \cdot ZPA \cdot \tfrac{1}{2}$$

The acceleration of the transformer tank cover and the turret is amplified in the bushing due to the air side mass (m_{as}), the natural frequenc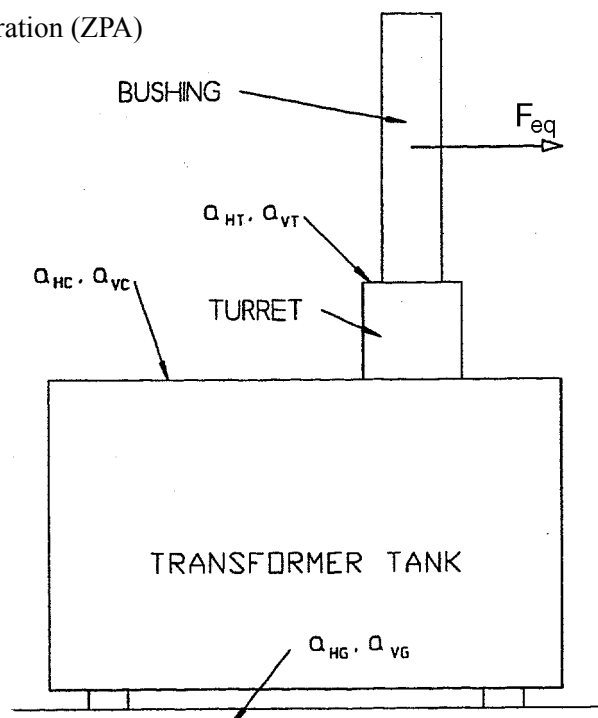y and the damping of the bushing, mounted on the transformer tank cover. This amplification or response, R (obtained from Table 1), together with the static coefficient, S_c, which takes into account the effects of both multi-frequency excitation and multimode response, gives rise to a force that affects the bushing in the bushing air side centre of gravity. If the bushing is mounted at angels to the vertical plane both the vertical and the horizontal parts of the earthquake will affect the bushing, see section 4.1.

$$F_{eq} = m_{as} \cdot a_{HT} \cdot R \cdot S_C = m_{as} \cdot ZPA \cdot K \cdot R \cdot S_C$$

where

m_{as} = Mass of bushing air side above the flange = the total mass of the parts of the bushing that is above the base of the insulator.

4 Seismic calculations

In all calculations in this pamphlet the vertical acceleration is affecting the bushing down-wards, that is to say in the same direction as the acceleration due to gravity, see Fig. 5. This generates the greatest loads on the bushing.
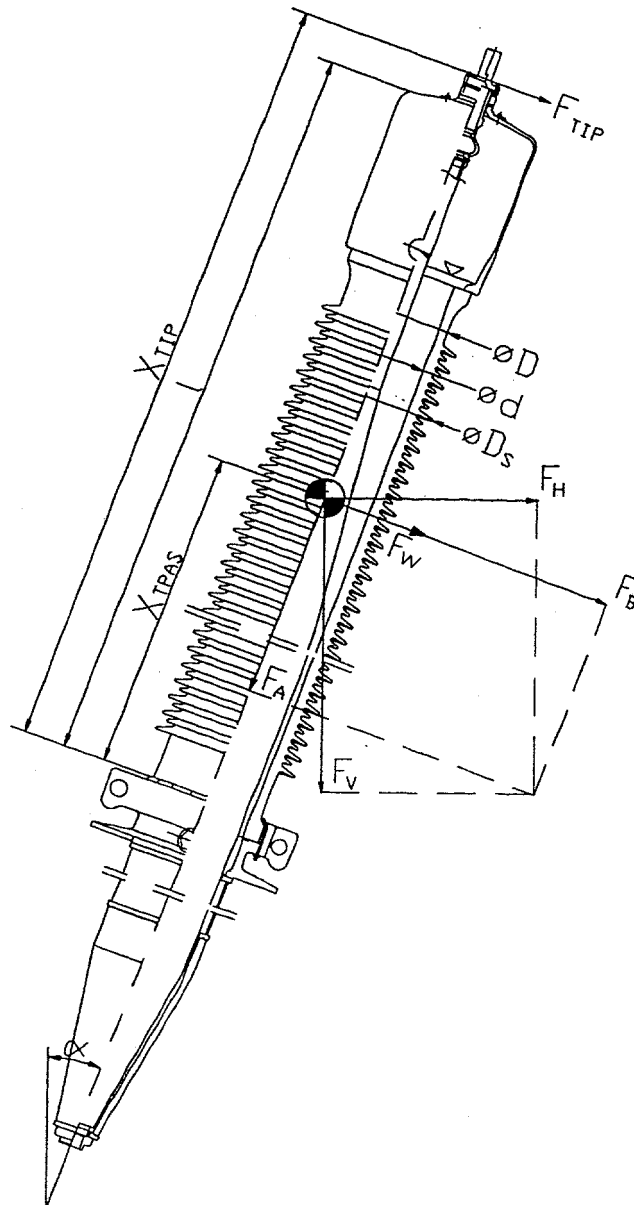

Fig. 5. All the forces affecting the mounted bushing and all the variables involved in the calculations on the bushing.

4.1 Seismic load

From Fig. 5 it can be seen that

F_H = Horizontal force due to an earthquake = $m_{as} \cdot K \cdot ZPA \cdot R \cdot S_C$

F_V = Vertical force due to an earthquake and due to gravity =

= $m_{as} \cdot K \cdot ZPA \cdot \frac{1}{2} \cdot R \cdot S_C + m_{as} \cdot g$

where

m_{as} = air side mass above the flange, can be taken from section 4.8

g = acceleration due to gravity = 10 m/s²

K = amplification factor = 1.5

ZPA = zero period acceleration, is depending on the seismic requirements

R = response factor = can be taken from Table 1

S_C = static coefficient = can be taken from Fig. 3 and section 3.2

Simple geometry from Fig. 5 gives that:

F_A = Compressive force = $(-F_H) \cdot \sin \alpha + F_V \cdot \cos \alpha$

F_B = Bending force = $F_H \cdot \cos \alpha + F_V \cdot \sin \alpha$

where α is the mounting angle to the vertical plane, see Fig. 5.

4.2 Wind load

Wind loads are considered as static loads. The following is valid for wind loads in general:

$$Fw = C_D \cdot A_{proj} \cdot P = C_D \cdot A_{proj} \cdot \rho \cdot \frac{v^2}{2}$$

where (see Fig. 5)

F_W = Wind force affecting the bushing in its air side centre of gravity

C_D = Drag factor = 1.0 for a cylinder

A_{proj} = Projected area above the flange = $\frac{(D_s + D)}{2} \cdot l$

ρ = Density of air = 1.28 kg/m³

v = Velocity of air

P = Wind pressure, it is decided by IEC that a wind pressure of 70 Pa may affect the bushing at the same time as an earthquake = 70 Pa. About equal to a wind velocity of 10 m/s.

The wind forces are accordingly varying depending only on projected area as the drag factor, the density of air and the velocity of air is the same for all the bushings. The wind forces for the different bushings can be seen in section 4.8.

4.3 Tip load

The permissible operating load, see Fig. 5, from the connecting line is different depending on mounting angle, rated current, rated voltage, and load class, stated in IEC 60137. The cantilever operating tip loads for the different bushings during a seismic event can be seen in section 4.8, taken from IEC 60137. A combination of the extreme values of all electrical and environmental service loads would lead to unrealistic conservatism. Therefore, it is prescribed by IEC that the tip load at an earthquake event is equal to 70 % of the cantilever operating load specified for the bushing. Accordingly only 70 % of the value in the table in section 4.8 shall be used.

4.4 Bending moment

The forces that are affecting the bushing as bending forces are:

F_B = Force due to an earthquake and due to gravitiy, see section 4.1 and Fig. 5

F_W = Force due to a wind pressure of 70 Pa, see section 4.2 & 4.8 and Fig. 5

F_{TIP} = Force from the connecting line, see section 4.3 & 4.8 (70 % of the value) and Fig. 5

These three forces give rise to a bending moment, M_b, at the top of the flange equal to, (see Fig. 5):

$$M_b = F_B \cdot x_{TPAS} + F_W \cdot x_{TPAS} + F_{TIP} \cdot x_{TIP} = (F_B + F_W) \cdot x_{TPAS} + F_{TIP} \cdot x_{TIP}$$

where

F_B can be obtained from section 4.1

x_{TPAS}, x_{TIP}, F_W and F_{TIP} (70 % of the value) can be taken from section 4.8.

4.5 Guaranteed bending strength

Cantilever load withstand tests have been performed for the bushings at ABB Components in accordance with IEC standards. It has been tested how much load at right angles to the terminal the bushing can withstand for 60 seconds without leakage or damage. As the duration of the peak accelerations in an earthquake is much shorter than 60 seconds this value of cantilever load withstand, F_{test}, can be used to compare with.

The cantilever load, F_{test}, is applied at the tip of the bushing and accordingly it gives rise to a bending moment, M_{test}, equal to:

$$M_{test} = F_{test} \cdot x_{TIP}$$

where F_{test} and x_{TIP} can be taken from section 4.8.

Now that the actual bending moment, M_b, and the guaranteed bedning strength, M_{test}, is calculated it is possible to say whether the bushing can withstand the expected earthquake or not. If the guaranteed bending strength, M_{test}, is greater than the actual bending moment, M_b, the bushing is capable to withstand the expected earthquake.

4.6 Bending stresses

When the porcelain is fixed by clamps or cemented to the flange, as for the bushing type GOE and GOE(2), it is possible that there are tensile stresses in the porcelain due to the bending moment, M_b. As the porcelain is sensitive to tensile stresses it can be good to check the stresses. Permitted bending stress in the porcelain when seismic calculations are made according to
IEC 61264 is the characteristics of the 100 % type test withstand on the hollow insulator used for the bushing in question. This value of permitted bending stress is given by the porcelain manufacturer.

The bending stress, σ_b, in the bushing is equal to $\quad \sigma_b = \dfrac{M_b}{W_b}$

where

$$W_b = \frac{\pi \cdot [D^4 - d^4]}{32 \cdot D} \qquad \text{and can be taken from section 4.8}$$

M_b can be taken from section 4.4

The bending stress consists of both tensile stress and compressive stress. The prestressal force, F_p, and the compressive force due to an earthquake and due to gravity, F_A, give rise to a compressive stress that decreases the tensile part of the bending stress and increases the compressive part of the bending stress generated by the bending moment.

The compressive stress, σ_p, generated by the compressive forces F_p and F_A:

$$\sigma_p = \frac{F_p + F_A}{A}$$

where

$$A = \frac{\pi}{4} [D^2 - d^2]$$

and can be taken from section 4.8

F_p can be taken from section 4.8

F_A may be obtained from section 4.1

The critical tensile part of the bending stress, $\sigma_{b, \text{tensile}}$, will then be decreased to:

$$\sigma_{b, \text{tensile}} = \sigma_b - \sigma_p$$

This value of the tensile part of the bending stress can then be compared with the permitted bending stress. If the permitted bending stress is greater than the tensile part of the bending stress, $\sigma_{b, \text{tensile}}$, the porcelain will withstand the bending moment.

4.7 Natural frequency

In section 3.2 there are discussions about the natural frequency of the bushing mounted on the transformer tank cover; if the natural frequency of the mounted bushing is not known one has to set the response factor, R, to the conservative value of the RRS-diagram. This gives a conservative value of the earthquake load on the bushing.

It is not so simple to obtain the natural frequency of the mounted bushing. Often one can consider the bushing as stiff and accordingly it is the "weakness" of the transformer tank cover that decides the value of the natural frequency. When the bushing is mounted on a turret the "weakness" of the turret may also affect the natural frequency of the mounted bushing.

The natural frequency and damping of the mounted bushing can be measured at a free oscillation test or they can be obtained from a FEM-analysis of the structure. Another alternative is to estimate the natural frequency from similar structures on which tests or FEM-analysis have been performed. For bushing mounted on transformer tank a damping value of 5% may be used without further justification (IEC 61463).

If the transformer manufacturer can tell the spring characteristic for the mounted bushing it is possible to calculate the natural frequency from fundamental equations:

$$\omega = \text{natural angular velocity} = \sqrt{\frac{c}{J}}$$

where

c = spring characteristic for the mounted bushing, given by the transformer manufacturer $(Nm \cdot (rad)^2)$

J = mass moment of inertia around the bottom of the flange, can be taken from section 4.8

The natural frequency can then be obtained from the following equation:

$$f = \text{natural frequency} = \frac{\omega}{2 \cdot \pi}$$

Now that the natural frequency is estimated and together with the damping value of 5 % it is possible to obtain a value of the response factor, R, from Table 1.

4.8 Bushing data

Table 2. Data needed for seismic calculations on the type GOB bushings.

Type GOB	Rated current A	Oil level gauge	Extended porcelain at top	m_{as} kg	F_W N	F_{TIP} [1] N	x_{TPAS} mm	x_{TIP} mm	F_{test} N	W_b mm³·10⁴	F_P kN	A mm²·10³	J kg·m²
250	800	N	N	17.9	5.1	500/300	225	630	2340	10.2	45	5.08	4
"	"	"	Y	19.1	6.2	"	278	730	"	"	"	"	4
"	"	Y	-	20.8	6.6	"	305	760	"	"	"	"	5
250	1250	N	N	20.1	5.6	625/375	261	675	4000	9.77	90	4.21	5
"	"	"	Y	21.6	6.7	"	285	775	"	"	"	"	5
"	"	Y	-	23.2	7.2	"	310	815	"	"	"	"	6
325	800	N	N	21.7	6.7	500/300	330	765	1950	10.2	45	5.08	7
"	"	"	Y	23.0	7.7	"	352	865	"	"	"	"	7
"	"	Y	-	24.7	8.1	"	380	905	"	"	"	"	8
380	800	N	N	27.0	7.7	"	356	820	1800	9.41	45	4.48	9
"	"	"	Y	28.2	8.8	"	376	920	"	"	"	"	10
"	"	Y	-	30.1	9.2	"	402	960	"	"	"	"	11
380	1250	N	N	30.5	7.9	625/375	362	875	3750	11.6	90	4.95	11
"	"	"	Y	31.8	9.0	"	383	975	"	"	"	"	12
"	"	Y	-	33.7	9.5	"	407	1015	"	"	"	"	14
450	800	N	N	35.7	9.8	"	441	990	1500	11.4	45	5.36	16
"	"	"	Y	36.7	11	"	459	1090	"	"	"	"	17
"	"	Y	-	39.7	11	"	485	1130	"	"	"	"	20
550	800	N	N	57.9	15	"	541	1200	1700	25.2	45	9.01	39
"	"	"	Y	59.8	16	"	560	1300	"	"	"	"	42
"	"	Y	-	62.7	17	"	590	1340	"	"	"	"	46
550	1250	N	N	68.7	16	800/480	548	1245	3100	29.1	90	8.38	50
"	"	"	Y	71.1	18	"	570	1345	"	"	"	"	52
"	"	Y	-	78.4	18	"	625	1385	"	"	"	"	60
650	1250	N	N	92.6	20	"	647	1445	3500	39.1	90	11.1	84
"	"	"	Y	96.2	21	"	667	1545	"	"	"	"	85
"	"	Y	-	102	22	"	717	1585	"	"	"	"	102
750	1250	N	N	146	28	"	748	1655	3350	91.2	90	20.9	169
"	"	"	Y	150	30	"	769	1755	"	"	"	"	178
"	"	Y	-	159	32	"	826	1905	"	"	"	"	203
1050	1100	Y	N	265	43	1250/750	1136	2515	6000	71.5	90	16.6	[2]

1) The higher value of F_{TIP} is used when the bushing is installed ≤ 30° from the vertical and the lower value is used when the bushing is installed > 30° from the vertical.

2) Calculate on request.

Table 3. Data needed for seismic calculations on the type GOE bushing.

Type GOE	m_{as} kg	F_W N	F_{TIP} [1] N	x_{TPAS} mm	x_{TIP} mm	F_{test} N	W_b mm³·10⁵	F_P kN	A mm²·10⁴	J kg·m²
250-210	123	16	1575/945	418	1005	5700	10.4	100	1.89	65/80
	139			409						74/94
380-300	165	22	2000/1200	545	1280	5700	"	"	"	121/139
	188			537						136/159
450-400	203	28	"	686	1575	5000	"	"	"	206/228
	234			678						235/261
650-500	235	32	"	770	1755	5700	"	"	"	297/329
	269			736						337/375
900-650	305	42	"	1012	2255	5000	"	"	"	591/631
	351			1006						673/719
1050-750	599	68	1575	1242	2735	13000	36.7	"	4.81	1778/1860/1957
1175-850	668	74	1575	1360	2975	12000	"	"	"	2410 [3]
	728		2500	1355						
1300-1050	847	100	1575	1803	3930	10000	"	"	"	4921 [3]
	931		2500	1797						
1300-1150	906	111	1575	2002	4325	9000	"	"	"	6303 [3]
	999		2500	1992						
1550-1050	1181	116	1575	1746	3840	16000	71.9	"	7.43	6718 [3]
	1263		2500	1743						
1675-1175	1358	132	1575	1991	4335	16000	"	"	"	9614 [3]
	1450		2500	1990						
1675-1300	1506	158	1575	2271	5135	13000	"	"	"	13800 [3]
	1616		2500	2267						
1800-1300	1506	"	1575	2271	"	13000	"	"	"	13900 [3]
	1616		2500	2267						
2100-1425	2185	208	1575	2818	6110	15700	111.1	190	9.16	29780 [3]
2550-1550	2360	632	1575	3088	6910	14000	"	"	"	38790 [3]
2550-1600	2515	691	1575	3329	7400	13000	"	"	"	47100 [3]

1) If there are more than one row with values of F_{TIP}, the upper row corresponds to the lowest current level for the bushing, and the lower row corresponds to the highest current level for the bushing. The higher value on a row is used when the bushing is installed ≤ 30° from the vertical and the lower value is used when the bushing is installed > 30° from the vertical.

2) If there are more than one row with values of m_{as}, x_{TPAS} or J, the upper row corresponds to the lowest current level for the bushing, and the lower row corresponds to the highest current level for the bushing. The first value on a row corresponds to the shortest flange extension, and the last value on a row corresponds to the longest flange extension.

3) J is given for flange extension 0.3 and I=2500 A. Other permissible values for flange extension or current will not change the value of J with more than 5 %.

Table 4. Data needed for seismic calculations on the type GOE(2) bushing.

Type GOE(2)	Cat. No.	m_{as} kg	F_W N	F_{TIP} N [1]	x_{TPAS} mm	x_{TIP} mm	F_{test} N	W_b mm³·10⁵	F_P kN	A mm²·10⁴	J kg·m²
1175-850	LF 121 560	491	62	1250	1548	3180	10000	12.7	100	2.08	1739 [1]
1425-1050	LF 121 570	659	79	1250	1874	3890	10000	12.7	100	2.08	3169 [1]
1675-1300	LF 121 580	895	104	1250	2134	4800	10000	19.5	100	2.83	5836 [1]

[1] J is given for flange extension 0.3. If flange extension 0.6 is used, the value of J will change, but not more than 5 %.

Table 5. Data needed for seismic calculations on the type GOH bushing.

Type GOH	Rated current A	m_{as} kg	F_W N	F_{TIP} N [1]	x_{TPAS} mm	x_{TIP} mm	F_{test} N	W_b mm³·10⁴	F_P kN	A mm²·10³	J kg·m²
170/10	10	49.5	8.1	1575/945	160	385	10000	69.5	45	12.8	6
170/16	16	82.2	11	"	155	"	"	152	55	20.1	10
170/25	25	128	14	"	155	"	"	278	75	25.8	18

[1] The higher value of F_{TIP} is used when the bushing is installed ≤ 30° from the vertical and the lower value is used when the bushing is installed > 30° from the vertical.

Table 6. Data needed for seismic calculations on the type GOM bushing.

Type GOM	Cat. No.		m_{as} kg	F_W N	F_{TIP} N [1]	x_{TPAS} mm	x_{TIP} mm	F_{test} N	W_b mm³·10⁵	F_P kN	A mm²·10⁴	J kg·m²
1050	LF 125 060	-A -G	308	46	800/480	1205	2500	3600	7.03	100	1.38	657
"		-B -H	"	"	"	"	"	"	"	"	"	670
"		-C -K	"	"	"	"	"	"	"	"	"	690
"		-D -L	357	53	"	1385	2850	3200	"	"	"	984
"		-E -M	"	"	"	"	"	"	"	"	"	997
"		-F -N	"	"	"	"	"	"	"	"	"	1015

[1] The higher value of F_{TIP} is used when the bushing is installed ≤ 30° from the vertical and the lower value is used when the bushing is installed > 30° from the vertical.

Table 7. Data needed for seismic calculations on the type GSA bushing.

Type GSA	Cat. No.	m_{as} kg	F_W N	F_{TIP} N [1]	x_{TPAS} mm	x_{TIP} mm	F_{test} N	J kg·m²
52	LF 130 052-BA	17.7	5.1	1000/600	284	567	2500	6
73	LF 130 073-BA	24.9	7.1	1000/600	359	747	3150	11
123	LF 130 123-BA	54.7	14.3	800/480	572	1167	3150	39
170	LF 130 170-BA	75.3	20	800/480	782	1587	4000	88

[1] The higher value of F_{TIP} is used when the bushing is installed ≤ 30° from the vertical and the lower value is used when the bushing is installed > 30° from the vertical.

5 Examples of seismic calculations

Example 1

Seismic calculations for a GOE 1300-1050-2500-0.3 (rated current 2500 A and flange extension 0.3) bushing, see Fig. 5, with permissible mounting angle of 0-30° mounted on a transformer tank. The bending moment generated by an earthquake is compared with guaranteed bending strength.

Seismic load: (see section 4.1)
The mounting angle from the vertical plane, α, is 10°
m_{as} = 847 kg (from section 4.8)
$g = 10$ m/s^2
$K = 1.5$
$ZPA = 3$ m/s^2 (the seismic requirement)
$R = 1.74$ (the conservative value from Table 1 as we do not know the natural frequency of the mounted bushing)
$S_C = 1.5$ (the conservative value from Fig. 3 as we do not know the natural frequency of the mounted bushing)

$F_H = m_{as} \cdot ZPA \cdot K \cdot R \cdot S_c = 847 \cdot 3 \cdot 1.5 \cdot 1.74 \cdot 1.5 = 9\ 948$ N
$F_V = m_{as} \cdot g + m_{as} \cdot 1/2 \cdot ZPA \cdot K \cdot R \cdot S_c = 847 \cdot 10 + 847 \cdot 1/2 \cdot 3 \cdot 1.5 \cdot 1.74 \cdot 1.5 = 13\ 444$ N
$F_A = (-F_H) \cdot \sin \alpha + F_V \cdot \cos \alpha = (-9\ 948) \cdot \sin 10° + 13\ 444 \cdot \cos 10° = 11\ 512$ N
$F_B = F_H \cdot \cos \alpha + F_V \cdot \sin \alpha = 9\ 948 \cdot \cos 10° + 13\ 444 \cdot \sin 10° = 12\ 131$ N

Wind load: (see section 4.2)
$F_W = 100$ N (from section 4.8)

Tip load: (see section 4.3)
$F_{TIP} = 1575$ N (from section 4.8) $\cdot$ 0.70 = 1 103 N

Bending moment: (see section 4.4)
$x_{TPAS} = 1803$ mm (from section 4.8)
$x_{TIP} = 3930$ mm (from section 4.8)

$M_b = (F_B + F_W) \cdot x_{TPAS} + F_{TIP} \cdot x_{TIP} = (12\ 131 + 100) \cdot 1\ 803 + 1\ 103 \cdot 3\ 930 = 26.4$ kNm

Guaranteed bending strength: (see section 4.5)

$F_{test} = 10000$ N (from section 4.8)

$M_{test} = F_{test} \cdot x_{TIP} = 10000 \cdot 3\ 930 = 39.3$ kNm

As the guaranteed bending strength, M_{test}, is greater than the actual bending moment, M_b, the bushing is capable to withstand the expected earthquake.

Example 2

Seismic calculations for the bushing in example 1. The actual tensile stresses in the porcelain generated by an earthquake is compared with the permissible tensile forces in the porcelain.

Bending stresses: (see section 4.6)
Permitted bending stress = 17 N/mm^2 (given by the porcelain manufacturer)
$M_b = 26.4$ kNm (from example 1)
$W_b = 36.7 \cdot 10^5$ mm^3 (from section 4.8)

F_A = 11 512 N (from example 1)

A = 4.81 · 10⁴ mm² (from section 4.8)

$$\sigma_{b} = \frac{M_b}{W_b} = \frac{26.4 \cdot 10^6}{36.7 \cdot 10^5} = 7.2 \text{ N/mm}^2$$

$$\sigma_{P} = \frac{F_p + F_A}{A} = \frac{100000 + 11512}{4.81 \cdot 10^4} = 2.3 \text{ N/mm}^2$$

$\sigma_{b, \text{tensile}} = \sigma_b - \sigma_p$ = 7.2 - 2.3 = 4.9 N/mm²

As the permitted bending stress is greater than the tensile part of the bending stress, $\sigma_{b, \text{tensile}}$, the porcelain will withstand the bending moment.

Example 3

Seismic calculations for the bushing in examples 1 and 2. The natural frequency of the mounted bushing is calculated and the response factor is estimated.

Natural frequency: (see section 4.7)
c = spring characteristic for the mounted bushing = 4.23 · 10⁷ Nm·(rad)² (given by the transformer manufacturer)
J = 4 921 kg·m²
Damping for bushing screwed on transformer tank = 5 %

$$\omega = \text{Natural angular velocity} = \sqrt{\frac{c}{J}} = \sqrt{\frac{4.23 \cdot 10^7}{4921}} = 92.7 \text{ rad/sec}$$

$$f = \text{Natural frequency} = \frac{\omega}{2 \cdot \pi} = \frac{92.7}{2 \cdot \pi} = 15 \text{ Hz}$$

With 5 % damping and 15 Hz natural frequency we obtain a response factor, R , of 1.56 from Table 1.

With 15.0 Hz natural frequency we obtain a static coefficient, S_c, of 1.31 from section 3.2 and Fig. 3:

$$S_c = 1 + 0.5 \cdot \frac{25 - 15}{25 - 9} = 1.31$$

From here the calculations proceed exactly as in example 1, but the response factor, R, is 1.56 instead of 1.74 and the static coefficient, S_c, is 1.31 instead of 1.5.

ABB