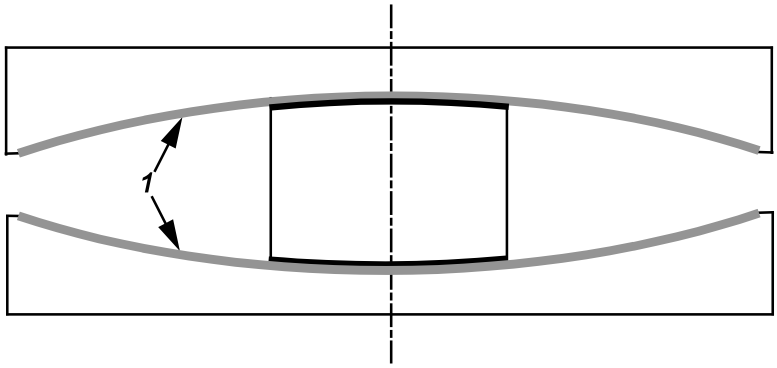
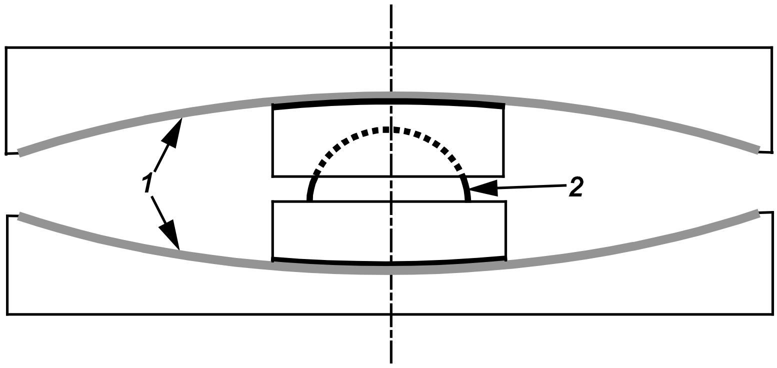



**Key**

1 primary sliding surfaces of the double Curved Surface Slider

**Figure 5 — Double Curved Surface Slider without hinge**




**Key**

1 primary sliding surfaces of the double Curved Surface Slider

2 hinge

**Figure 6 — Double Curved Surface Slider with hinge**

#### 8.3.1.2.5 Maximum frictional resistance to service movements

Static friction resistance is the maximum force necessary to produce macroscopic motion during the first movement (see EN 1337-2:2004, 3.2.3) and is considered in the design of the isolator, its anchoring system and the adjacent structural members.

During the movements occurring under service conditions, the Curved Surface Sliders shall not develop a frictional force higher than the value given in the Design Specifications.

Friction shall not be used to relieve the effects of externally applied horizontal forces other than earthquake induced forces (see also EN 1337-2:2004, 6.7).

Curved Surface Sliders may incorporate restraint devices that resist wind or other external loads induced motions in one or all directions and that release the device for full motion in case of earthquake (see 5.3 Fuse Restraints).

The value of the frictional force shall be checked by tests in accordance with 8.3.4.1.3. The measured breakaway frictional force developed by the isolator shall be less than the value given in the Design Specifications.

A specimen made of sliding material shall be subjected to a long-term friction test in accordance with 8.3.4.1.4. The total sliding path *s*t shall be declared by the manufacturer and shall not be less than 10 000 m for bridges and 1 000 m for buildings or an equivalent type of structure. The maximum coefficient of friction for each temperature and contact pressure as determined from the long-term friction tests shall be reported, and used to define the design values of the maximum frictional force (see 8.3.3.4.2).

#### 8.3.1.2.6 Isolation characteristics

Dynamic friction is the mechanism through which energy dissipation is achieved by the Curved Surface Slider. Therefore, the dynamic coefficient of friction is of crucial importance in determining the response of the seismic isolation system.

Tests in accordance with 8.3.4.1.5 shall be carried out.

Test O therein shall be requested only if the austenitic steel sheet is manufactured with, e.g. seams because of its large size. Three cycles shall be completed as specified in Table 17, in a direction of motion perpendicular to the seams.

The force-displacement curves for all tests specified in Table 17 shall show an increasing horizontal force. The austenitic steel mating spherical sheet shall not show any sign of buckling, permanent deformation or dislocation.

The following requirements for tests specified in Table 17 shall be met:

Test S – Service Conditions:

The maximum recorded horizontal force shall not exceed the value given in the Design Specifications.

Tests D1, D2, D3 – Dynamic Conditions:

1) There shall not be more than ± 10 % change in the Restoring Stiffness between successive cycles;

2) For each cycle, the Restoring Stiffness of the upper portion of the cycle shall be within 10 % of the value obtained for the lower portion;

3) The average of the Restoring Stiffness for the three cycles shall be within ± 20 % of the design value;

4) The maximum horizontal force for each of the three cycles shall be within ± 20 % of the design value;

5) The Energy Dissipated per Cycle H (EDC) for each cycle shall not be less than 80 % of the design H, evaluated at the design displacement;

6) The Restoring Stiffness of each cycle and its average of one specimen shall be within ± 20 % of the same stiffness of the other specimen.

Test O – Integrity of overlay:

— The requirements of test D3 shall apply. In addition, the test specimen shall be free of cracks and any sign of damage.

Test E – Seismic Condition:

— The same acceptance criteria indicated for Dynamic Conditions tests shall apply.

Test B – Bi-directional:

— No sign of buckling, permanent deformation or dislocation of the austenitic steel sheet shall occur.

Test P1 – Benchmark for Factory Production Control test

Test P2 – Property Verification:

— The requirement for the Service Conditions test shall apply.

Test P3 – Benchmark for ageing influence:

— The change of frictional force compared to the result of test P1 shall be considered in the design.

Under all loading conditions the movement in the sliding surfaces shall be smooth and without producing any type of vibrations such as those induced by the stick-slip phenomenon.

The average restoring stiffness shall be obtained from the best-fit straight line determined by the least square interpolation of the response between ± 85 % of the peak test displacement. The fluctuation of the horizontal force shall be within a range of ± 5 % of the average restoring force, at any level of slider displacement up to 85 % of the peak test displacement.

The coefficient of friction and all the related performance parameters shall fall within the limits given in the Design Specifications under the testing conditions specified in 8.3.4.1.5.

The temperature, ageing and service life dependent upper and lower bound design values referred to in 4.5.2 shall be based on the results of the long-term friction tests as per 8.3.4.1.4. It shall be assumed that the ratio between these values is equal to the ratio between the dynamic coefficient of friction $\mu_{\mathrm{dyn,max}}$ and $\mu_{\mathrm{dyn,min}}$ at the end of phase B taking into account the upper and lower bound service temperatures, $T_{\mathrm{U}}$ and $T_{\mathrm{L}}$, respectively, determined on the basis of quasi-permanent values as defined in EN 1991-1-5 (see 4.5.2). The influence of ageing on the coefficient of friction shall be taken from the ageing test result as per 8.3.4.1.6.

NOTE Service life dependence is understood as the change in long-term friction behaviour due to the accumulated sliding under service conditions.

#### 8.3.1.2.7 Wear resistance

The sliding interfaces are the critical components of Curved Surface Sliders and their retention of performance after a major earthquake avoids the need for immediate maintenance interventions or, more seriously, a rehabilitation intervention.

The scope of this verification is to show the isolator’s capacity to survive protracted actions during its service lifespan as well as the occurrence of a seismic attack.

Creep deformation is significant and its effect is subtracted from the observed thickness reduction in order to evaluate the extent of the wear correctly. In the absence of more precise measurements, the change in thickness of the sliding material layer after 48 h of constant loading without sliding movement can be taken as the creep deformation correction to be applied.

The wear of the sliding surfaces during their service life and at the occurrence of a design basis earthquake shall be limited in such a way that there is an adequate safety margin for the correct functioning of the Curved Surface Slider in accordance with the tests given in 8.3.4.1.4 and 8.3.4.1.5. The following requirements shall be met:

a) the reduction in thickness of the sliding material shall be measured using one or more displacement transducers with a minimum accuracy of 0,05 mm, prior to and following the Type Testing and corrected for the effect of creep during the tests, shall not exceed 20 % of the initial thickness;

b) the depth of any scratch produced by scoring of the austenitic steel surface shall be less than 0,05 mm;

c) the deformation of the backing plates shall be limited in such a way that the maximum deviation Δz from theoretical curved surface within the area of the mating sliding sheet shall not exceed 0,000 3 × $L$ or 0,2 mm, whichever is greater. $L$ is the diameter of the circumscribing circle of single or multiple sliding material sheets (see EN 1337-2:2004, Figures 3, 4 and 5 for clarification of the definition).

### 8.3.2 Materials

#### 8.3.2.1 Sliding material

Materials suitable for curved sliding surfaces of structural bearings in accordance with 8.1 shall be used.

For primary sliding surfaces, undimpled sheets without lubrication may be used.

#### 8.3.2.2 Mating surfaces

For mating surfaces austenitic steel with thickness of at least 2,5 mm in accordance with EN 10088-2:2014, 1.4401 + 2B or 1.4404 +2B or backing plates with at least 100 µm hard chromium plating according to EN ISO 6158 or other materials suitable for curved surfaces of structural bearings in accordance with 8.1 shall be used. The surface characteristics of the primary sliding surface shall be defined by the manufacturer and considered in the sliding behaviour tests as per 8.3.4.1.4 and 8.3.4.1.5. If the primary sliding surface has the function to provide energy dissipation as well as isolation, the requirements for its surface characteristics, that is roughness $R_Z$ in accordance with EN ISO 4287 and hardness according to EN ISO 6507-2, shall be declared by the manufacturer.

The surface characteristics of the secondary sliding surface and primary sliding surface not required to provide energy dissipation shall be in accordance with EN 1337-2:2004, 5.4 and 5.5.

Type Tests and Factory Production Control tests on each batch of material shall be performed to verify that the requirements are met.

#### 8.3.2.3 Lubricants

If the sliding surface is lubricated, the lubricant shall be in accordance with EN 1337-2:2004, 5.8.

#### 8.3.2.4 Backing plates

Steel plates in accordance with EN 10025, (all parts) cast iron in accordance with ISO 1083, cast carbon steel in accordance with ISO 14737 or stainless steel in accordance with EN 10088 (all parts) shall be used for the backing plates, as appropriate.

The substrate for hard chromium plated sliding surfaces shall be steel grade S 355 J2G3 or fine grain steel of the same or higher grade in accordance with the EN 10025 series.

### 8.3.3 Design

#### 8.3.3.1 Load bearing capacity

The load bearing capacity shall be verified in accordance with EN 1337-7:2004, 6.3.1 and 6.3.3.

For spherical sliding surfaces with an included angle $2\theta \leq 60°$, and for cylindrical sliding surfaces with an included angle $2\theta \leq 75°$ the method of stress verification shall be in accordance with the method given in EN 1337-7.

For secondary spherical sliding surfaces with an included angle $2\theta > 60°$ and secondary cylindrical sliding surfaces with an included angle $2\theta > 75°$, compressive stress verification shall be conducted using appropriate calculation methods, such as Finite Elements Modelling.

NOTE A valid simplified method for calculating stress distribution in spherical and cylindrical isolator surfaces within the linear-elastic range is shown in Annex I.

Sliders shall fulfil the requirements for structural bearings in accordance with 8.1. For example, for PTFE the requirements are given in EN 1337-2:2004, Clause 5, 6.2, 6.6, 6.8, 6.9, 7.1, 7.2.

#### 8.3.3.2 Horizontal displacement capacity

The mating surface dimensions of the primary sliding surface shall be so proportioned that in all conditions they completely cover the primary bearing sliding material.

#### 8.3.3.3 Rotation capacity

The mating surface dimensions of the secondary sliding surface shall be so proportioned that in all conditions they completely cover the secondary bearing sliding material.

#### 8.3.3.4 Friction resistance

##### 8.3.3.4.1 General

During movements of Curved Surface Sliders, friction develops in both the primary and secondary sliding surface. Notwithstanding, the requirements for the two surfaces are different, inasmuch as friction in the primary sliding surface serves to dissipate energy, whilst in the secondary sliding surface friction is minimized to ensure proper distribution of pressure on the sliding materials.

##### 8.3.3.4.2 Maximum frictional force

The static coefficient of friction $\mu_{\max}$ shall be used for verification of the isolator and the structure in which it is incorporated. The design value of the maximum frictional force is given by the following formula:

$$F_{xy,d} = -\mu_{\max} N_{Sd} \, sign(\dot{d}_b) \tag{25}$$

where

| | |
|---|---|
| $N_{\mathrm{Sd}}$ | is the normal force on the device under non-seismic design conditions |
| $\mathrm{sign}(\dot{d}_{\mathrm{b}})$ | is the sign of the velocity $(\dot{d}_{\mathrm{b}})$, and |
| $d_{\mathrm{b}}$ | is the relative displacement of the two sliding surfaces. |

a) Primary sliding surface:

The values of static coefficient of friction $\mu$max are obtained from long-term friction tests as per 8.3.4.1.4. The design values for different pressure levels are the maximum values measured in the phases A, C and D at the end of the test at various pressures. Intermediate values shall be obtained by linear interpolation or through Formula (27).

For pressures below 0,08 $f_k$ or above 0,33 $f_k$, where $f_k$ is the characteristic compressive strength of the sliding material (see EN 1337-2:2004, Table 10), the coefficient of friction shall be assumed equal to the threshold values.

The design temperature $T_L$ is the frequently occurring low temperature as defined in EN 1990:2002, 1.5.1.3.17 and shall be given in the Design Specifications. In the absence of more precise values, $T_L$ = −10 °C for bridges and 0 °C for buildings shall be used.

b) Secondary sliding surface:

When lubricated PTFE is used as sliding material, its coefficient of friction shall comply with EN 1337-2:2004, 4.1. The coefficient of friction of sliding materials not complying with that subclause shall comply with the values permitting their use in structural bearings in accordance with 8.1.

For example, PTFE sliders shall fulfil the requirements given in EN 1337-2:2004, Clause 4, Clause 5, 6.1, 6.5, 6.7, 7.5.

**8.3.3.4.3 Sliding Isolation**

The behaviour of the isolator during an earthquake is governed by the frictional and geometrical characteristics of the primary sliding surface. See also EN 1337-7:2004, A.2.1.

The upper and lower bound values of the dynamic coefficient of friction shall be used for the design and verification of the isolator as well as the dynamic analysis of the structure.

**8.3.3.5 Backing plates**

Backing plates shall be designed and verified in accordance to EN 1337-2:2004, 6.9 adapting Formula (6) to the used sliding material.

They shall be made out of solid elements, without lightening hollows and ribs.

**8.3.3.6 Separation of sliding surfaces**

It shall be verified that the contact pressure $\sigma_p \geq 0$ under all load combinations at serviceability limit state. For the verification, the sliding material shall be assumed to be linear elastic and the backing plates are deemed to be rigid.

Separation of the sliding surfaces may lead to wear due to contamination and increased deformation of the sliding material because of faulty confinement of the latter. As this could jeopardize long-term fitness for use, the condition $\sigma$p = 0 is considered as the serviceability limit state.

For spherical sliding surfaces with an included angle 2θ ≤ 60°, the condition $\sigma_p \geq 0$ is satisfied at the serviceability limit state when the total eccentricity $e_t$ satisfies the relation:

$$e_t \leq \frac{L}{8} \qquad (26)$$

where

$L$ is the diameter of the projected area.

NOTE The method for calculating the eccentricities in spherical and cylindrical surfaces is given in Annex I.

For spherical sliding surfaces with an included angle 2θ > 60°, the verification of the condition $\sigma_p \geq 0$ shall be conducted using suitable calculation methods such as the simplified method shown in Annex I or Finite Element Modelling.

The above requirements do not apply to non-lubricated sliding surfaces.

### 8.3.4 Testing

#### 8.3.4.1 Type Testing

##### 8.3.4.1.1 General

Tests shall be carried out on the Curved Surface Slider and samples of sliding materials to demonstrate the satisfaction of the general performance characteristics specified in 8.3.1.2.

NOTE The test programme involves a substantial total energy input to the Curved Surface Slider. Therefore, care is required in the execution of the test programme to ensure that any tests performed in quick succession will not excessively overheat the isolator. To hold the latter in check, the temperature at the centre of the primary bearing sliding material needs to be monitored and reported. It is advisable to divide the test programme into groups of tests. After having performed one test or one group of tests, the isolator is allowed to cool to a temperature specified by the manufacturer before performing the subsequent test group.

The tests listed in this subclause may be performed in an order different from that presented.

The tests shall be arranged into groups in accordance with the criterion that the total energy input to the Curved Surface Slider in each group of tests does not exceed 1,5 times the energy dissipated by the isolator during a design level earthquake.

If entrance and exit cycles are required for the correct execution of the test, the related energy input shall be taken into account.

The tests shall be performed at a temperature of (23 ± 5) °C, unless some other temperature is specified in 8.3.4 or in the Design Specifications. Experimental results obtained from tests on similar Curved Surface Sliders (reference devices) that satisfy all the requirements of this clause may be used for new devices provided:

1) design displacement of the new Curved Surface Slider is within ± 20 % of the reference design value;

2) bearing capacity of the new Curved Surface Slider is within ± 30 % of the reference design value $N_{Sd,ULS}$;

3) design coefficients of friction are the same for new and reference Curved Surface Slider;

4) basic materials for sliding elements are the same for new and reference Curved Surface Slider;

5) the radius of curvature of both primary and secondary curved surfaces is within ± 20 % the reference design value.

Prior to performing these tests, the Curved Surface Slider shall be subjected to a 10-min pre-loading with the maximum normal load $N_{Sd,SLS}$, where $N_{Sd,SLS}$ is the action effect of the characteristic combination of actions according to EN 1990.

At the end of the pre-loading time, the thickness of the sliding material shall be measured using at least three displacement transducers with a 0,05 mm accuracy. This set of values shall represent the benchmark values for further verifications.

For safety reasons the thickness measurement may be carried out by electronic sensors or replaced by measurements on unloaded devices, if appropriate conversion rules for the loaded condition are available.

NOTE If the sliding material is recessed in its backing plate, "sliding material thickness" is the protrusion of the sliding material sheet from its recess.

#### 8.3.4.1.2 Load bearing capacity

The scope of this test is to verify the overload capacity of Curved Surface Sliders.

The loading history of the test shall be the following: at zero displacement, apply a load equal to 1,3 $N_{\mathrm{Sd,ULS}}$ (see 8.3.1.2.2) and maintain it constant for 1 min. A continuous plot of the vertical force vs. displacement shall be recorded.

#### 8.3.4.1.3 Frictional force under service conditions

The scope of these tests is to verify the maximum horizontal force developed by the isolator under service conditions.

Loading history: At zero displacement, apply a vertical load equal to the characteristic permanent load $N_{\mathrm{Sd}}$ according to EN 1990 and keep it constant for 30 min, then impose a horizontal displacement with a sliding velocity $v \leq 0{,}1$ mm/s for 1 min. The horizontal force and the displacement shall be continuously recorded.

#### 8.3.4.1.4 Static coefficient of friction

This subclause describes the method for determining the static coefficient of friction of material samples, as well as the wear resistance of the primary curved sliding surface where no lubricant is used. The principles of verification, the terms and definitions as well as the test equipment and specimens are given in EN 1337-2:2004, Annex D.

A long-term friction test with the programme in accordance with Table 15 shall be carried out under the following conditions:

**Table 15 — Long-term friction test programme**

| **Phase Number** | **1** | **2** | **3** | **4** | **5** |
|---|---|---|---|---|---|
| Type | A | B | A | C | D |
| Distance | 22 m | $s_{\mathrm{t}}$ | 22 m | 22 m | 22 m |

Specimen: Mating surface and sliding material for structural bearings in accordance with 8.1

Diameter of sliding material specimen $L$ = 75 mm

In the phases A, C and D the static coefficients of friction shall be measured at the different temperature levels indicated in Table 16 and Figure 7.

**Table 16 — Friction test conditions**

| **Type A (phases 1 and 3), C (phase 4), D (phase 5) ... Temperature – Programme – Test** | | | |
|---|---|---|---|
| Contact pressure of sliding material | $\sigma_{\mathrm{p}}$ | Type A: $0,33\,f_{k}\,{}^{+3}_{0}$<br>Type C: $0,17\,f_{k}\,{}^{+3}_{0}$<br>Type D: $0,08\,\mathrm{f_k}\,{}^{+3}_{0}$ | MPa |
| Temperature | $T$ | 0/-10/-20/-35/+35/+21 (±1) | °C |
| Temperature gradient | | From 0,5 to 1,0 | °C / min |
| Preload time | $t_{\mathrm{pl}}$ | 1 | h |
| Stroke | $s_{\mathrm{A}}$ | $10\,{}^{+0,5}_{0}$ | mm |
| Dwell time at the end of the strokes | $t_{0}$ | 12 ± 1 | s |
| Number of cycles (two strokes) | $n$ | 1 100 | |
| Sliding speed | $v$ | $0,4\,{}^{+0,1}_{0}$ | mm / s |
| Dwell between phases | $t_{\mathrm{i}}$ | 1 | h |
| **Type B (phase 2)** | | | |
| Contact pressure of sliding material | $\sigma_{\mathrm{p}}$ | $0,33\,\mathrm{f_k}\,{}^{+3}_{0}$ | MPa |
| Temperature | $T$ | 21 ± 1 | °C |
| Temperature gradient | | From 0,5 to 1,0 | °C / min |
| Stroke | $s_{\mathrm{B}}$ | $8\,{}^{+0,5}_{0}$ | mm |
| Number of cycles (two strokes) | $n$ | $n = \frac{s_t}{2s_B}$ | |
| Sliding speed | $v_{\mathrm{a}}$ | ≥ 2 | mm/s |

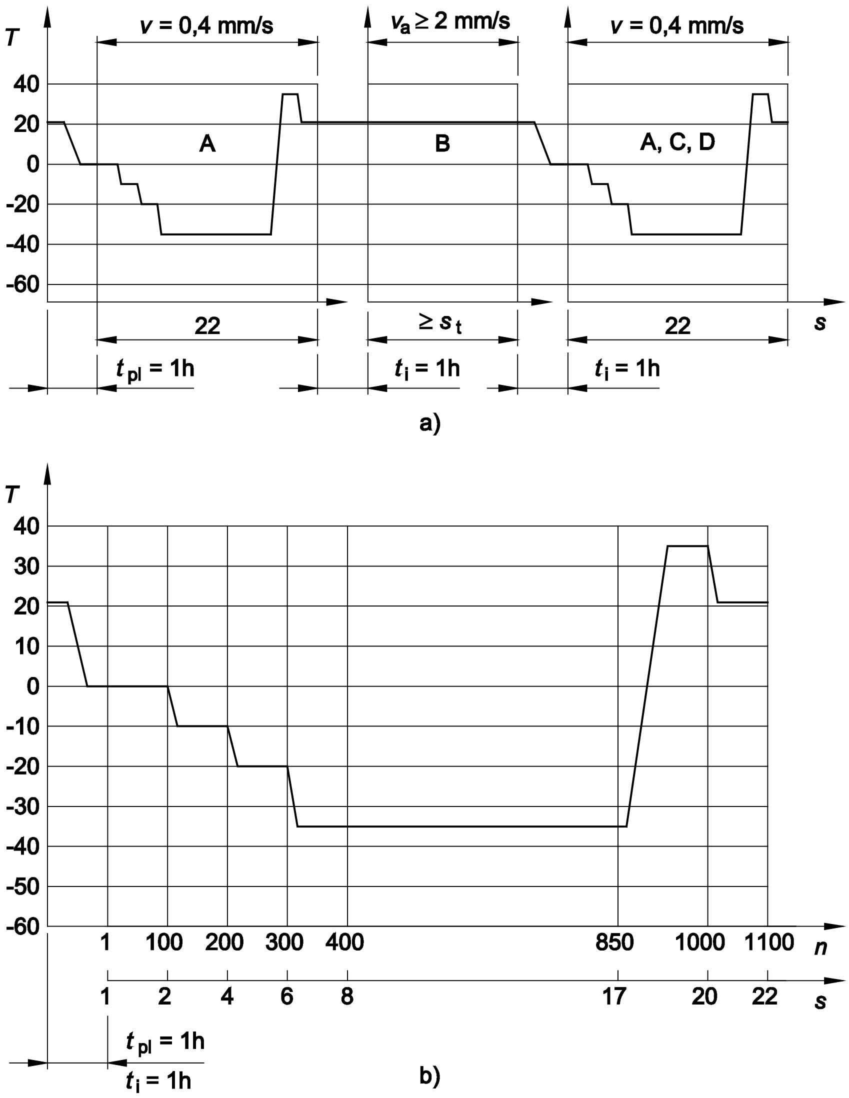



**Figure 7 — Temperature profile of the long-term sliding test**

If the minimum temperature, $T_{min}$, for the intended use is extended to – 50 °C the temperature range in the Temperature Programme Test shall be extended as shown in Figure 8. If the minimum temperature, $T_{min}$, for the intended use is higher than the temperature of some sections of the Temperature Programme Test, during those sections the temperature shall be kept constant and equal to $T_{min}$.

NOTE $T_{min}$ is the lowest likely service temperature and is not identical to $T_L$.

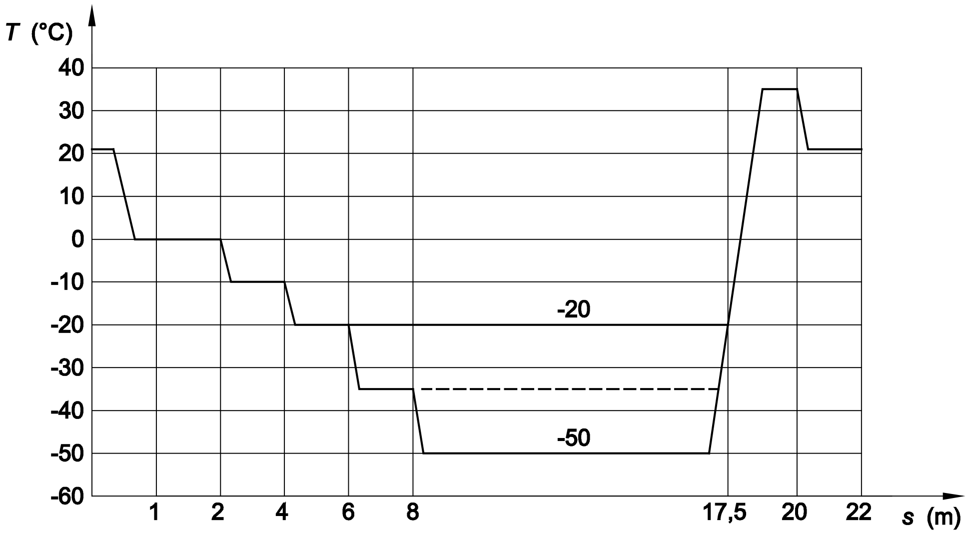



**Figure 8 — Example of Temperature programme of the long-term sliding test for $T_{min}$ = – 50 °C and $T_{min}$ = – 20 °C**

#### 8.3.4.1.5 Sliding tests

The scope of these tests is to verify the dynamic behaviour of Curved Surface Sliders in terms of coefficient of friction, damping capacity and stability under repeated cycling.

The sliding tests shall be conducted in accordance with the test matrix provided in Table 17.

NOTE 1 For sliding materials used in the Curved Surface Slider, the relationship between the coefficient of friction μ and the pressure $\sigma_p$ is given by the expression:

$$\mu = f(\sigma_p) \tag{27}$$

As an example for thermoplastic materials the following expression may be used

$$\mu = \frac{C}{\sqrt{\sigma_p}} \tag{28}$$

where

$C$ depends on the type of sliding material used, roughness of mating surfaces, temperature, velocity etc. Other expressions taking into account additional parameters may be used.

The displacement input waveform shall be sinusoidal:

$$d(t) = d_0 \cdot \sin(2\pi \cdot f_0 \cdot t) \tag{29}$$

The frequency $f_0$ [Hz] shall be calculated considering the effective radius of curvature $R_{eff}$ [m] of the Curved Surface Slider according to the classical formula:

$$f_0 = \frac{1}{2\pi}\sqrt{\frac{g}{R_{eff}}} \tag{30}$$

where $g$ is the gravity acceleration equal to 9,81 m/s$^2$. The testing peak velocity is calculated according to the following formula: