Table 13.11.9-2 — Operating parameters for shock arrestors

Parameter	Values (at room temperature)
Activation velocity range	2 mm/s to 6 mm/s
Bleed velocity range (if applicable)	0,2 mm/s to 2 mm/s
Operating frequency range	0,5 Hz to 33 Hz
Control valve release (where applicable)	The greater of 200 N or 2 % of the rated load
Drag load maximum (at 0,5 mm/s)	The greater of 200 N or 2 % of the rated load
NOTE The lost motion during load reversal (from clearance in the bearings and as a result of the physical mode of operation) should not exceed 0,5 mm.	

13.11.10 Clamps for shock arrestors, rigid struts

Clamps for dynamically loaded supports such as shock arrestors and rigid struts shall be designed according to 13.11.4.3. In the creep range area, when determining f for only dynamically loaded supports, the value for the design stress in the creep range f_{cr} can be replaced by the stress to cause 1 % permanent elongation $S_{1\%\ 10\ 000t}$ at 10 000 h in accordance with the following Equation (13.11.10-1):

$$f_D = \min\left(\frac{R_{eHt}}{1{,}5} or \frac{R_{p0{,}2t}}{1{,}5}; \frac{R_m}{2{,}4}; S_{1\%10\,000t}\right) \quad (13.11.10\text{-}1)$$

where

f_D is the maximum permissible stress for dynamically loaded clamps;

$S_{1\%\ 10\ 000t}$ is the mean value of the stress which leads to a 1 % creep elongation in 10 000 h at the considered temperature t.

Annex A
(informative)

Dynamic analysis

A.1 General

In addition to the static conditions and cyclic pressure and temperature loadings covered by 4.2, piping may be subjected to a variety of dynamic loadings. Dynamic events should be considered in the design of the piping. However, unless otherwise specified, such consideration may not require detailed analysis. The effects of significant dynamic loads should be added to the sustained stresses in the design of the piping. Continuous dynamic loads should be considered in a fatigue analysis.

Where the dynamic event produces reverse forces, it may be acceptable to derive maximum loadings by combining those forces whose direction makes them additive to the static loads. However, care should be taken regarding the displacements as both plus and minus movements may be needed for layout and supporting detail design.

There are a number of methods for the calculation of the effect of dynamic events, such as:

a) simplified static equivalent;

b) quasi-static equivalent;

c) shock response spectra modal analysis;

d) force time history.

Experience has shown that for properly supported piping, the use of simplified methods generally leads to acceptable engineering solutions for the prevention of damage during dynamic events. Where complex analysis is to be undertaken, care should be exercised in the selection of suitable programmes and consistent data for the derivation of forces and allowable loads.

Piping and piping components may also be analysed by subjecting full or part scale models to a vibratory regime comparable to the expected dynamic loading.

A.2 Analysis by calculation

A.2.1 Seismic events

A.2.1.1 General

Seismic events produce vibratory ground movements which are transmitted through the building structure to piping and other equipment. The structure and equipment respond by undergoing accelerations and displacements whose magnitude varies with their stiffness and natural resonance frequencies.

The analysis of the interaction of the building structure with the seismic driving forces is not within the scope of piping design and the associated response will normally be supplied by the purchaser or site owner, following earthquake assessment and structural analysis of the proposed building.

An analysis of the piping should be carried out to show the maximum forces and moments generated within the piping as a result of the structures response to the predicted earthquake.

The type of calculation determines the form and extent of seismic data to be made available to the piping designer.

A.2.1.2 Simplified static equivalent analysis

This method ignores the variation in the structure's response at different frequencies and damping rates, and calculates the displacements and forces in the piping using a single equivalent static accelerating force for each principal direction of seismic movements. This acceleration is based upon the maximum value arising from the earthquake. It may be presented to the designer as a ground base response spectrum, or calculated for each level within the building structure, or given as a single set of responses which are considered to envelope the different responses applicable to the piping.

Where no building related accelerations are available, the designer should use the peak ground acceleration as the maximum acceleration a_i.

The static equivalent acceleration, a_{cqi}, for direction i is calculated as follows:

$$a_{cqi} = k_i \; a_i \tag{A.2.1-1}$$

where

a_i is the maximum acceleration defined for the level in direction i;

k_i is a factor;

- $k_i = 1$ where the natural frequencies of the piping can be shown not to coincide within 10 % of the peak vibration frequencies in the response spectrum of the structure;
- $k_i = 1{,}5$ where no check on the coincidence of piping and building vibration characteristics has been undertaken.

A.2.1.3 Quasi-static equivalent analysis

This calculation applies a single static acceleration for each of the directions of the ground vibration equivalent to the highest acceleration in the building response spectrum which can excite the piping. For this method, the significant natural frequencies of the piping should be calculated.

The quasi-static equivalent acceleration $a_{qe\,i}$ for direction i is calculated as follows:

$$a_{qe\,i} = \bar{k}_i \; a_{fi} \tag{A.2.1-2}$$

where

a_{fi} is the maximum acceleration in the ground or level vibration spectrum at frequencies greater than or equal to the first own frequency of the piping;

$\bar{k}_i$ is a factor related to the contributions of multiple own frequencies for the shape of the piping system.

The factor $\bar{k}_i$ should be determined from Table A.2.1-1. Lower values of the factor may be used where their admissibility is demonstrated.

Table A.2.1-1 — Values of $\bar{k}_i$

Model	$\bar{k}_i$
Multi supported linear beam with equal span lengths	1,0
Cantilever beam	1,0
Single beam supported at both ends (maximum forces are to be applied at every cross section)	1,0
Single plane systems, e.g. frames, girder systems, single plane piping	1,2
3 dimensional systems with complex shapes	1,5

For rigid piping (i.e. where the lowest own frequency of the system is higher than or equal to the cut-off frequency of the ground vibration spectrum) the value of $\bar{k}_i$ may be taken as 1,0.

For the determination of support reactions, the value of $\bar{k}_i$ may be taken as 1,0 irrespective of which model is used from Table A.2.1-1.

A.2.1.4 Modal response spectra analysis

For modal response spectra analysis, the piping designer requires a building response spectrum for each level/location within the structure, or a spectrum which can be considered to envelope the responses within the structure. This modal response spectrum is derived from the maximum accelerations generated by the earthquake at differing frequencies over an appropriate period of time, and their interaction with the building structure. Vibration analysis of the piping should be carried out to determine the displacements, moments, and forces for the imposed accelerations at each significant frequency in the modal spectrum.

The total response of the piping (displacements, moments, forces) for each direction should be obtained by combining each peak modal response by the square root of the sum of the squares (SRSS) method, i.e.

$$R_i = \pm\sqrt{\sum_{m=1}^{n} R_{mi}^2} \quad \text{(A.2.1-3)}$$

where

R_i is the total response in the principal direction i;

R_{mi} is the peak response due to the mode m;

n is the number of significant modes.

The combination of piping responses from the three principal directions should be based on the following assumptions:

- the piping responses to different building modal peaks do not occur at the same time;
- peak responses do not occur simultaneously in the three principal directions;
- peak stresses due to the different modes do not generally occur in the same place in the piping.

Consequently the maximum response of the system need not be calculated by applying the SRSS method to the three orthogonal directional maxima.

A.2.1.5 Force time history analysis

Where seismic displacements of the supporting structure are known with respect to time, the dynamic response of the piping system can be determined. This is done by imposing the pattern of accelerations or displacements at the support and terminal point locations onto a suitable model of the piping which incorporates the stiffness and masses of the piping and appropriate dynamic damping factors. The resultant stresses can be determined for the piping displacements as a series of calculations at discrete time intervals.

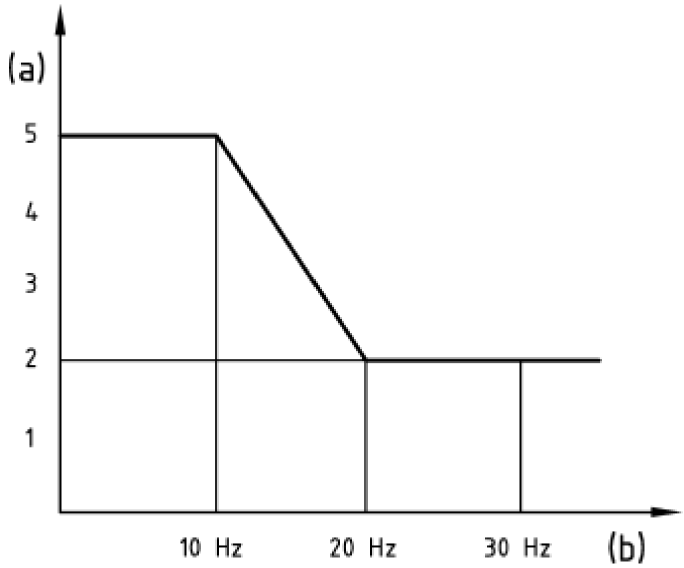
Various mathematical programmes are available for the solution of the dynamic problems, and the designer should ensure that the model and analytical methods are appropriate.

The time intervals should be chosen to ensure that no significant short term excitation is missed, and the number of steps should ensure that all significant displacements are included in the analysis.

The seismic stresses in each of the three principal directions should be combined using the SRSS method for each time step, and the highest resultant values generated during the seismic event should be added to the sustained loads to determine the total stress for design purposes.

A.2.1.6 Damping values

Vibration in piping and structures is subject to energy dissipation or damping. Sources of damping arise from the internal friction of the materials, imperfect connections between components, sliding friction, and other features. The assessment of the extent of damping for particular sources is complex and specific, so that for the purpose of this Annex the graph given in Figure A.2.1-1 should be used for those methods of dynamic analysis incorporating damping, unless other appropriate and reliable data is available.



Key

For all sizes of pipe:

(a) critical damping in %

(b) frequency in Hz

Figure A.2.1-1 — Damping for seismic events

A.2.1.7 Seismic support displacement

The effect of relative movement of supports and anchors during seismic events should be considered in the calculation of the total stresses. For piping supports in the same level of a single building, these effects may be small, but where there is no coupling between parts of the supporting structure, the relative displacements can be significant.

In such cases, the designer should use the absolute sum of the displacements at anchors in each of the three principal directions (discounting signs). As an alternative, detailed force time history analysis of the supporting structure may be used to determine the maximum relative displacements and consequent stresses. It should be noted that these relative movement stresses are self limiting and secondary.

A.2.2 Rapid valve closure

A.2.2.1 General

If the flow of a fluid in a piping system is interrupted by the rapid closure of a valve downstream of the source of the flow, a pressure wave can be generated in the fluid, travelling back from the valve to the source. Such a wave will interact with the piping and will be reflected from the source to create complex pressure patterns within the system. In multi-branched systems, these patterns are further influenced by waves travelling in pipes meeting others out of phase. Vibration is caused by the differential wave pressures generated in the system creating out of balance forces in the piping which can take several seconds to decay. This is called water hammer.

For this phenomenon to occur, the action of the valve will be sufficiently fast for it to close in less time than it takes for a wave travelling at sonic speed in the fluid to travel from the valve to the source and be reflected back to the valve. This is called rapid valve closure.

The way in which a valve closes can vary from one type to another. It is generally assumed that the rate of reduction of area is constant over a substantial part of the stroke with final closure at a reduced rate to minimise impact on valve seating. Such a tail to the closing curve will increase the total closure time with generally beneficial results for the effect of water hammer.

It should be noted, however, that fluid flow will not have the same characteristic curve, being proportionately higher than the area reduction at the same point in time. Consequently, the valve may close by a large proportion of its area without significantly reducing the fluid flow. Those calculations which model the valve closure characteristics need particular care in this respect.

The rise in pressure should be calculated to ensure that the piping can withstand the combined sustained and shock pressure stresses. Additionally, the magnitude of the out of balance forces should be determined and applied to the design of the piping to calculate the stresses within the pipes and nozzles, and at connections to the supporting structure.

In addition to the calculation of the forces in the system, the designer should determine the movement of the piping under this forced vibration to ensure adequate clearances.

It should be noted that in addition to the pressure wave upstream, there may be a rarefaction wave created downstream of the closing valve, and the resulting vacuum effects should be assessed.

NOTE Attention is also drawn to the effects of the sudden opening of valves. On the upstream of the valve similar effects to those due to valve closure may be seen due to a front of lower pressure passing backwards up the pipe. In the piping downstream of the valve, unbalanced momentum and pressure forces will act by turn on each section of straight pipe as the fluid or its pressure front progresses.

A.2.2.2 Simplified static analysis of rapid valve closure

This method considers only the initial pressure rise in the system following valve closure and assumes the stresses caused by this to be the maximum that the system will experience. It ignores the interactions and damping of the waves and the dynamic response of the system to the vibration. The analysis is conservative and can lead to an over protection of the piping which may conflict with the thermal or other design criteria.

a) Pressure rise assessment

Closure is rapid if the following equation is satisfied:

$$T < \frac{2L}{v_\mathrm{s}} \qquad \text{(A.2.2-1)}$$

where

— L is the length of the system;

— T is the effective valve closure time;

— v_s is the sonic velocity in the fluid.

The initial rise in pressure dP is given by:

$$\mathrm{d}P = v_\mathrm{s}\ v\ \rho \qquad \text{(A.2.2-2)}$$

where

— v is the velocity of the fluid;

— ρ is the density of the fluid under the calculation conditions.

NOTE This is Joukowsky' s formula.

The sonic velocity may be calculated as:

$$v_{\text{s}} = \sqrt{\frac{k}{\rho}} \tag{A.2.2-3}$$

where

k is the fluid bulk modulus.

For piping with significant elasticity, this may be modified to:

$$v_{\text{s}} = \sqrt{\frac{1}{\rho\left(\frac{1}{k} + \frac{D_{\text{o}}}{eE}\right)}} \tag{A.2.2-4}$$

The designer should ensure that the minimum design pipe wall thickness can withstand the operating pressure plus the maximum dynamic pressure rise dP.

b) Static assessment of dynamic loads

The effects of imbalance or surges on the piping system may be assessed by applying a calculated pressure differential to the ends of straight runs of pipe or at changes in direction. The differential pressure is the proportion of the peak pressure developed over the piping length under consideration and it is assumed to act over the internal area of the pipe. In calculating the resulting forces, factors should be applied which makes allowance for the variation in closure rate throughout the valve stroke and the dynamic nature of the actual loadings.

The maximum out of balance load, F, in a length of pipe section, L, may be calculated as follows:

— for stiff piping

$$F = 2\frac{M}{A}\frac{L}{\lambda}\,\text{d}P\,\pi\,\frac{D_{\text{i}}^2}{4} \tag{A.2.2-5}$$

— for flexible piping

$$F = 4\frac{M}{A}\frac{L}{\lambda}\,\text{d}P\,\pi\,\frac{D_{\text{i}}^2}{4} \tag{A.2.2-6}$$

$$\lambda = v_{\text{s}}T \tag{A.2.2-7}$$

$$L/\lambda\; M/A \leq 1 \tag{A.2.2-8}$$

where

λ is the wavelength of the pressure wave;

M is the maximum rate of valve area closure;

A is the average rate of closure determined by the total closure time.

A.2.2.3 Advanced methods of calculation

The characteristics and effects of the pressure wave created by rapid valve closure may also be assessed by time history or modal analysis.

The development of the pressure pulse throughout the piping system can be idealised using mathematical modelling of the events, and these pressures used at a large number of time intervals to determine the forces at terminals, or changes of direction. The forces thus derived can be used as the driving factor in an analysis of the vibrational response of the piping to these forces.

If modal analysis is used, the designer should check that the cut off frequency does not exclude any significant higher modes resulting from the interaction of waves in the piping, as the system can be relatively stiff for these frequencies.

These advanced methods may incorporate coupling between the fluid and the piping and can thus incorporate the damping of the pressure wave by the transfer of energy to relatively stiff piping. For steam, or similar fluids where the mass of the fluid is negligible relative to that of piping, the advantage of the use of the advanced method is small.

Whilst these methods offer a potentially more accurate and less conservative solution to the problem of rapid valve closure, the advanced techniques for rapid valve closure analysis can be very sensitive to the modelling of the fluid source, the valve characteristics, the supports, and the fluid behaviour. The designer should be satisfied that the mathematical representations of all aspects are suitable and accurate.

A.2.2.4 Damping values

Vibration in piping and structures is subject to energy dissipation or damping. Sources of damping arise from the internal friction of the materials, imperfect connections between components, sliding friction, and other features. The assessment of the extent of damping for particular sources is complex and specific, so that for the purpose of this Annex the graph given in Figure A.2.1-1 should be used for those methods of dynamic analysis incorporating damping, unless other appropriate and reliable data is available.

A.2.3 Flow induced vibration

A.2.3.1 General

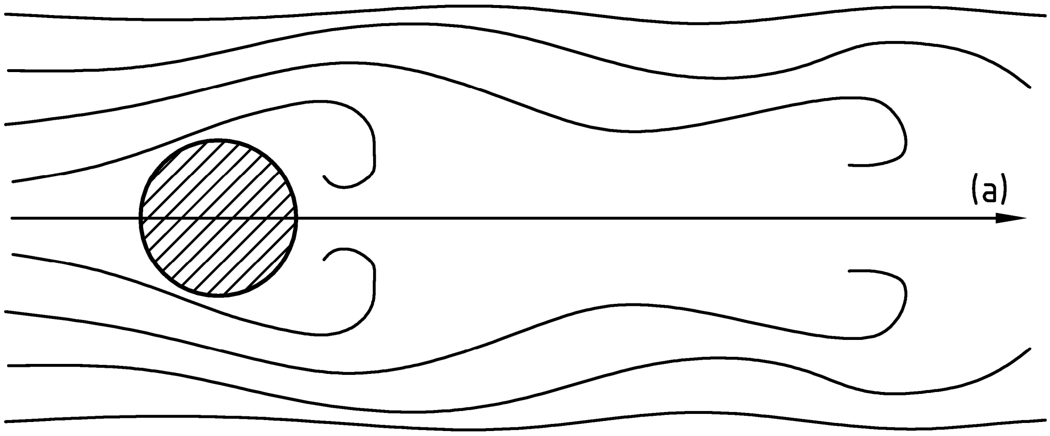
Disturbances to the smooth flow of fluids in piping systems can cause vibrations to be set up in the fluids. The fluid vibration can be transferred to the piping itself and in some circumstances large amplitude oscillations can be generated.

A piping system can be subject to a number of sources of excitation simultaneously and complex analysis may be required to assess the effect of these and the subsequent influence on the piping. Much of the data required to predict pipe movement is derived from experimental work and relates to particular conditions and geometry.

Unless reliable and appropriate data and mathematical models are available, the designer should consider the general mechanisms and problems posed by the more significant sources of flow related vibration in the design of the piping, and be prepared to make modifications if problems are experienced in operation.

A.2.3.2 Vortex shedding

The presence of a body in the path of fluid flow will create vortices downstream which are formed on alternate sides of the object in a regular pattern. This phenomenon will be found both internally, caused by the piping, and externally, caused by the passage of fluid (including wind) over the piping. A typical vortex pattern for a cylinder in a flow path is shown in Figure A.2.3-1. Such a pattern can be formed by a tube set into the flow, for example a thermometer or other measuring device. Similar patterns can be formed by arrays of tubes across the flow or non-circular shapes such as flat plates (in butterfly valves).



Key
(a) Flow

Figure A.2.3-1 — Typical vortex pattern

These vortices create an alternating force on the object normal to the flow and a smaller oscillating force in the direction of the flow.

The frequency, f_F, of the main force, F, can be expressed for a cylindrical object as:

$$f_F = S \frac{v}{D} \qquad \text{(A.2.3-1)}$$

where

v is the velocity of the fluid;

D is the diameter of the cylinder;

S is the Strouhal Number which comes from appropriate literature.

S = 0,2 may be used for fluids with a Reynolds number between 10^3 and 2×10^5.

The magnitude of the force *F* may be expressed as:

$$F = C\, J\, \frac{1}{2}\, v^2\, D\, L\, \sin(2\pi\, f_F T) \qquad \text{(A.2.3-2)}$$

where

L is the length of the system;

C, J and f_F are functions of the Reynolds number and need to be established for the fluid properties from appropriate literature or by experimental procedures.

Where the frequency of the vortex force lies within approximately ± 25 % of the natural frequency of the object in the flow, the two frequencies can tend towards synchronisation and large amplitude resonance can develop. The transmission of these vibrations to the piping depends upon the coupling of the object to the fluid and the pipe wall.

The strength of the vortex lift effect will be reduced in practice by turbulence around the object, by surface roughness disturbing the smooth flow of the fluid, by tapering the object, and by inclining the object to the flow. The proximity of other objects in the flow may also break up the development of strong vibrations.

A.2.3.3 Pump induced fluid pulsing

The operation of pumps does not generally produce a completely uniform delivery or suction pressure. The nature of the pressure variation in the fluid is dependent on the characteristics of the pump and the operating conditions.

Where possible, the designer should consider the layout of piping close to pumps, to dissipate the energy of the pulses and to avoid sharp changes of direction and the development of sympathetic vibration in the pipes.

If the frequency spectrum of the fluid pulses at the pump outlet is known, the response of the piping to this excitation can be modelled and analysed by either of the main methods of dynamic analysis. If such calculations are to be undertaken, the designer should ensure that the data and models accurately represent the operating conditions.

A.2.4 Safety valve discharge

A.2.4.1 General

The discharge of a safety valve will produce a reaction load on the piping to which it is connected. The initial rapid opening of the valve produces a dynamic component to the force which can be significant.

The effect should be treated as a localised event producing point loading at the nozzle connecting the valve to the piping, and should be incorporated into the design of the piping and the supporting arrangements. Where more than one valve is incorporated into a header, the designer should consider the reaction effects of combinations of valves opening.

Whilst it is possible to incorporate the valve opening characteristics into a mathematical model of the valve and discharge piping to determine the reaction force, it is generally satisfactory for atmospheric discharge to carry out a simple static analysis for the steady state and to apply a dynamic load factor.