Refer to the EMJA Standards for design, installation and use of expansion bellows.

Refer also to EN-13480, part 3, section 6.5, for piping to be installed in Europe.

If no vendor information is available regarding the effective pressure trust area of the bellow, then the mean bellow diameter should be used in the calculation for the cross sectional area where the pressure is applied. This area is always greater than the area represented by the pipe’s outer diameter.

There must be a strong anchor or line stop on either side of the broken pipe to take the large pressure thrust forces. Bellow spring force and friction forces from sliding pipe supports should also be included in the pipe support anchor calculations.

One of these line-stops or anchors should be as close to the expansion-joint as practical. Piping should be guided with spacing according to vendor specifications.

The use of expansion-joints for offshore installations should be minimised and always be approved by the owner/operator.

Expansion-Joints should never be applied to ring-main firewater or piping with hydrocarbons that are going to be designed for an accidental blast.

**3.10.2 Slip- joint thrust load**

Slip-joints are commonly used for cargo-piping systems on oil tankers. They are small in size and can take large pipe axial movements arising from temperature variations, loading-and offloading and vessel deck-deflections do to sag-and hog of the hull due to large waves passing underneath the vessel.

The pipe’s outer diameter should always be used in the calculation for the cross sectional area where the pressure is applied.

There must be a strong anchor or line stop on either side of the broken pipe to take the large pressure thrust forces. Bellow spring force and friction forces from sliding pipe supports should also be included in the pipe support anchor calculations.

One of these line-stops or anchors should be as close to the slip-joint as practical. Piping should be guided with spacing according to vendor specification.

The use of slip-joints for offshore installations should be minimised and always be approved by the owner/operator.

Slip-Joints should never be applied to ring-main firewater or piping with hydrocarbons that are going to be designed for an accidental blast.

Extreme care should be carried out when a mixing of so-called internally axial restrained- and open (no internal axial restraining) couplings of type “Straub pipe couplings”, which are not pressure-balanced, and similar designed couplings are being used on the same line. Although not advised, the first may be used without pipe line stops or anchors, whereas the latter must have pipe line-stops or anchors in order to take the end-cap forces from the internal pressure.

Extreme care shall also be provided if expansion-and slip-joints are being used on piping systems that should maintain their integrity after an accidental blast. Typical systems are firewater ring main and piping containing large amount of hydrocarbons. The reason is that it is difficult to calculate the differential displacements between the pipe support anchors or line-stops after an explosion and that such calculations have to be accurate within e.g. 50-100 mm differential displacement of the pipe support anchors in order to maintain the integrity of the joint. Hence expansion-and slip-joints should not be allowed on piping that have to maintain the integrity after an explosion.

### 3.11 Blast load calculations

#### 3.11.1 General

Evaluation of the structural integrity of piping and pipe supports during, and after, an accidental blast, or any other exceptional event, should always be performed by comprehensive methods such as FE pipe stress analysis. It should be noted that international research work is ongoing in order to come up with a method for the blast effect on piping that takes both the blast overpressure and the dynamic drag load into consideration. For smaller pipe sizes there will only be the load from the dynamic drag pressure, but for larger pipe diameters and pressure vessels there will also be a component from the overpressure in front of the blast. There is no international agreement on the exact pipe sizes where elements from the overpressure should be considered. The methodology to calculate the total reaction forces on the piping is also outstanding. This RP will be updated with a more comprehensive design philosophy when the international research work has concluded. Hence this RP only considers the traditional method which is to ignore the overpressure and design for the dynamic drag pressure alone. For further information it is recommended to visit the FABIG web-pages.

For accidental and/or exceptional load cases not covered by the codes the stress engineer/safety engineer should agree on a set of rules and limitations together with the owner and the third party verificator. Modification projects may include a variety of existing piping systems and equipment which differ largely with regards to what loads they have been designed for previously. Some modification projects consist of tying in new pipe to systems never designed for a blast scenario. For these projects an agreed blast procedure will benefit all parties.

#### 3.11.2 Accidental blast loads and allowable stresses

Pipe stress blast loads should be performed in two steps:

**a) Blast wind calculations**

Calculation of pipe stresses, support and equipment nozzle loads due to the blast wind (dynamic drag pressure) alone.

- ASME B31.3: The stress limit for this event will be the occasional stress limit = 1.33 x Basic allowable stress at temperature. (The PED harmonised piping code EN 13480 allow for 1.8 x basic allowable stress at temperature. The same utilisation should be allowed for in PED projects where the ASME B31.3 piping code is used instead of the harmonised piping code)

- EN 13480: The stress limit is 1.8 x basic allowable stress at temperature.

**b) Impact from deformation of structural steelwork**

Pipe stress calculations, flange integrity and equipment nozzle loads due to permanent displacement of pipe supports connected to primary and secondary steelwork that undergo a plastic deformation have to be performed. Typical are decks at different levels that deform permanently in opposite direction of each other due to the blast overpressure.

- ASME B31.3: The allowable stress for this event is higher than for the blast wind as this case can be considered analogue to a pipe settlement scenario, ref ASME B31.3 para. 319.2.1 (c). Hence an allowable stress equal to the “liberal equation”, ASME B31.3 para. 302.3.5 (d) (1b) should be allowed for. Alternatively the allowable operating stress as outlined in ASME B31.3, Appendix P, can be used. This alternative rule allows for a stress range up to 2.5 x basic allowable stress at moderate temperatures.

- EN 13480: For PED projects no stresses can exceed the allowable stresses calculated according to EN 13480, section 12.3.6. (Minimum of 3 x basic allowable stress or 2 x proof strength at temperature).
3.11.2.1 Blast drag pressure

A conservative rule of thumb in early design studies is to assume that the drag pressure is 1/3 of the blast overpressure. This gives conservative estimates up to an overpressure of approximately 2 bar. Thereafter the thumb of rule is non-conservative.

Table 3.1 below shows actual wind speeds that result in the same pipe drag loads as the dynamic drag pressure listed in the same table. The equivalent wind-air-density used in calculations below is 1.224 kg/m$^3$ which are a default density of air used by most pipe stress programmes in calculations of wind loads. (A sudden wind-gust of 20 m/s will knock a person over. This equals a dynamic drag pressure of only 0.0025 bar).

If no other information is available, blast drag loads should be considered to occur from all main directions, also downwards, e.g. through deck-grating. It is however not required to analyse two independent blast events happening at the same time, e.g. due to two ignition sources perpendicular to each other.

In order to obtain more reliable values for the overpressure and drag pressure for an offshore installation with steelwork, piping, firewalls, equipment etc a 3D blast event simulator should be used. The FLACS (FLaME ACceleration Simulation) programme is a commonly used software tool for such simulations.

<table>
<thead>
<tr>
<th>Explosion Overpressure [bar]</th>
<th>Dynamic Drag Pressure [bar]</th>
<th>Equivalent Wind Speed for Drag Load Calculations [m/s]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.2</td>
<td>0.02</td>
<td>57</td>
</tr>
<tr>
<td>0.4</td>
<td>0.05</td>
<td>90</td>
</tr>
<tr>
<td>0.6</td>
<td>0.10</td>
<td>128</td>
</tr>
<tr>
<td>0.8</td>
<td>0.15</td>
<td>157</td>
</tr>
<tr>
<td>1.0</td>
<td>0.21</td>
<td>185</td>
</tr>
<tr>
<td>1.2</td>
<td>0.28</td>
<td>214</td>
</tr>
<tr>
<td>1.4</td>
<td>0.36</td>
<td>243</td>
</tr>
<tr>
<td>1.6</td>
<td>0.45</td>
<td>271</td>
</tr>
<tr>
<td>1.8</td>
<td>0.55</td>
<td>300</td>
</tr>
<tr>
<td>2.0</td>
<td>0.65</td>
<td>326</td>
</tr>
<tr>
<td>2.2</td>
<td>0.76</td>
<td>352</td>
</tr>
<tr>
<td>2.4</td>
<td>0.88</td>
<td>379</td>
</tr>
<tr>
<td>2.6</td>
<td>1.00</td>
<td>404</td>
</tr>
<tr>
<td>2.8</td>
<td>1.13</td>
<td>430</td>
</tr>
<tr>
<td>3.0</td>
<td>1.27</td>
<td>456</td>
</tr>
<tr>
<td>3.2</td>
<td>1.41</td>
<td>480</td>
</tr>
<tr>
<td>3.4</td>
<td>1.57</td>
<td>506</td>
</tr>
<tr>
<td>3.6</td>
<td>1.73</td>
<td>532</td>
</tr>
<tr>
<td>3.8</td>
<td>1.88</td>
<td>554</td>
</tr>
<tr>
<td>4.0</td>
<td>2.05</td>
<td>579</td>
</tr>
</tbody>
</table>

Tabulated pressures are based on figure 5.3 in FABIG Technical Note No 8, Protection of Piping Systems Subjected to Fires and Explosions. This table is only meant for information and to show that the relationship between overpressure and drag pressure is not linear.

Typical estimates of blast overpressure for a variety of offshore installations and areas are listed in DNV-OS-A101 Safety Principles and Arrangements, table D1.

3.11.2.2 Blast drag load

Hand calculations of the blast drag load per unit length of the pipe can be calculated as follows:

$$F_D = \frac{1}{2} \cdot \rho \cdot v^2 \cdot D \cdot C_D \cdot DLF$$

where

- $F_D$ = Drag load from the blast per unit length (N/m)
- $\rho$ = density of the combustion gases (kg/m$^3$)
- $v$ = velocity of the combustion gases (m/s)
- $D$ = pipe diameter including insulation (m)
- $C_D$ = Drag coefficient for blast = 1.0 (Ref. 3.11.2.5)
- DLF = Dynamic Load Factor (Ref. 3.11.2.6)

The term $1/2\rho v^2$ equals the dynamic drag pressure used to calculate the equivalent air velocities in table 3.1 above.

3.11.2.3 Blast and operational flexibility

It should be noted that it is difficult and time-consuming to design for a blast drag load higher than 0.5 bar, especially for piping that requires flexibility in the operating condition, such as pipe spools close to gas-compressors and turbines that require low nozzle loads and hence very flexible piping that includes use of spring supports. Piping around such equipment may have to be designed with a double set of pipe supports, one for the operating condition and one for the accidental condition. Double sets of pipe supports should however be agreed with the operator in order to ensure that supports for the blast conditions are not mistakenly treated as operational supports. This could be a serious safety issue during normal operating condition, e.g. if required gaps on a guided blast support are overseen and closed by the welder. Hence blast supports should be painted with a specific colour.

3.11.2.4 Blast and structural deformation

Structural steel-work is by most design codes allowed to have plastic hinges and hence structural steelwork that pipe supports are welded to, may see large plastic deformations. Considerable structural deformation and equipment movement during explosion shall be taken into consideration in the piping design. This may require that some pipe supports may have to be designed with a weak-link, or breaking pin, that breaks when the structural steelwork deflects more than a certain limit and hence protects the piping from being overstressed and piping to leak. Typical situations are vertical piping being supported at two different deck levels where the two decks deflect in opposite directions during the explosion.

3.11.2.5 Blast drag coefficient, $C_D$

There is an international understanding that the drag coefficient for the blast combustion gases can be much higher than normally selected by use of typical steady-and turbulent flow diagrams and Reynolds numbers. The tabulated blast equivalent wind-velocities would by use of such diagrams typically result in $C_D$ values for piping in the range 0.6-0.7. These diagrams are, however, not valid for a fluid that accelerates, such as a blast wind.

API RP 2F. Recommended Practice for the Design of Offshore Facilities against Fire and Blast Loading, recommends that a drag coefficient, $C_D = 1.0$, should be used for blast load calculations of piping, and hence a $C_D = 1.0$ is the recommended value for blast design in this RP.

3.11.2.6 Dynamic Load Factor for blast, DLF

If no dynamic analysis or modal analysis to find the DLF for use in static analysis is carried out, then a conservative DLF in the range 1.5-2.0 should be used in order to account for the dynamic effect of a blast.

Dynamic Load Factors which are closely linked to the natural frequencies of the pipe span can be found in the British Steel Construction Institutes Document No, 209 “Interim Guidance Note, Section 3, Design Guidance for Explosion Resistance, 1992”.

For a triangular pulse which starts at zero and reaches a maximum value at 30% of the total blast duration time ($t_d$), the maximum response as a function of rise time to natural period (T) is shown in Figure 3.1 below.
From modal analysis the pipe stress engineer has found that the first mode of vibration for a given pipe span has a natural frequency, \( f_n = 20 \text{ Hz} \), corresponding to a periodic time, \( T = 1/f_n = 1/20 = 0.05 \text{s} \). The Dynamic Load Factor are then found by calculating the \( T_{d}/T \) ratio = 0.15/0.05 = 3.0. From Figure 3.1 below it can be seen that the corresponding DLF is approximately 1.0 which is far less than a conservative value of 1.5-2.0 chosen as default for all piping systems when modal analysis is not used.

**Figure 3.1**

DLF selection figure used in example above

### 3.12.2 Vibration

The allowable pipe design stress and Young’s Modulus for the blast condition should be adjusted to reflect the design temperature and not the properties at room temperature. Blast analysis should be carried out in combination with the total deadweight of the piping and the internal design pressure. Thermal expansion stresses will normally not contribute much to the total stresses as this is a secondary self-limiting stress. Thermal expansion stresses are therefore often ignored in blast analysis.

### 3.12 Fatigue calculations

#### 3.12.1 General

The pipe stress and flexibility analysis should normally be extended to a formal or simplified fatigue analysis when there is more than one additional cyclic load source of importance to the expansion-and contraction or alternating bending stresses of a piping system, e.g. other sources than pure temperature cycles which is taken care of by the equation for displacement stress calculations in most piping design codes and thereby automatically accounted for in the "code check" section of commonly available pipe stress programmes. Design and construction must ensure that due consideration is given to the risk of fatigue due to vibrations in pipes. A Modal analysis of all piping systems should be performed and it is desirable and a common practice to keep the piping system’s natural frequency above 4Hz to mitigate circumstances where fatigue can be induced by low frequencies of vibration. For situations where large expansion loops are required to absorb large movements, natural frequencies above 4Hz may be difficult to achieve.

#### 3.12.2 Vibration

Vibration effect on the fatigue life of the piping is to be examined when piping is connected to machinery such as reciprocating pumps and compressors. Blow-down and flare piping where high gas velocities are expected may be exposed to high frequency (acoustic) fatigue. One usual way to overcome acoustic fatigue is to increase the pipe wall thickness for a calculated specific length.

Vibration caused by wind induced vortex shedding is described in Appendix A of this recommended practice. Recommended procedures used in order to screen and avoid vibration-caused fatigue in piping are given in Guidelines for the Avoidance of Vibration Induced Fatigue in Process Pipeline, Second edition March 2008, published by the Energy Institute, London. (ISBN 9780 852934630).

### 3.12.3 Typical piping exposed to fatigue

Piping systems that by default should be analysed or evaluated for fatigue damage are:

- Piping connected to wellhead or Xmas trees where flexible hoses or "chiksan" type coupling are not used to take the vertical and horizontal movements.
- Piping along a bridge between two platforms, especially at the sliding landing area of the bridge.
- Piping running along the deck of a FPSO or in pipe racks along the FPSO that are subjected to vertical sag-and-hog deflections from loading and unloading waves. If no specific project data is available, a longitudinal compression-and-expansion of +/− 10 mm per 10 m pipe from the piping fixed point should be used for final design. Actual design values must be verified later in the project.
- FPSO piping-spool's with large unsupported overhang, poorly supported valves and valve-actuators, etc. that are subjected to vessel accelerations from sea actions (heave, pitch and roll accelerations).
- Piping connected to reciprocating pumps and compressors where low forced frequencies that could coincide with the natural frequency of the piping system.
- Thin walled duplex steel piping exposed to high gas velocities, so called acoustic fatigue.

### 3.12.4 Fatigue analysis of wellhead flowlines

Wellhead flowlines must be subjected to a comprehensive fatigue analysis given the fact that they are exposed to high cycle loadings from Xmas tree movements and flow induced vibrations. As ASME B 31.3 only to a limited degree takes into account fatigue damage, a more detailed fatigue calculation according to PD5500 should be performed for all flowlines and gas lift lines.

Wave loadings at the conductors initiate cyclic loads at the Xmas trees and an additional fatigue check should be performed.

The flow induced loads with the largest contribution to the fatigue life are not the design slug loads, but rather loads generated by minor density fluctuations in the well stream. These flow induced loads are not applicable for gas lift or water injection lines.

According to PD5500, the fatigue assessment shall be based on the primary plus secondary stress category and the full stress range is to be used.

The design lifetime of flowlines and gas lift lines should be 30 years unless otherwise specified by Company. Frequent inspection should be initiated after 1/3 of the estimated lifetime.

Frictional effects in pipe supports may be significant in fatigue analysis since they tend to increase the system resistance to Xmas tree movements, ref EN13480 12.2.10.3.1. These effects tend to be of importance in systems where there are one or more supports (not spring only) relatively close to the Xmas tree and where no line stops prevents the lines from moving relatively to the other supports.