6 Planning and construction guidelines and stress types

In principle, several internal and/or external stresses can affect a pipe system. This especially applies to buried pipe systems. Potential types of stress will be discussed below.

6.1 Internal and external pressure loads

In a pressure pipe system, principal stresses occur in various directions under the effects of compressive loads (internal and external overpressure, or internal underpressure). In principle, the below-listed types of stress can be distinguished:

- Radial stress (σ_r)
- Axial stress, longitudinal stress (σ_a)
- Tangential stress, circumferential stress (σ_t)

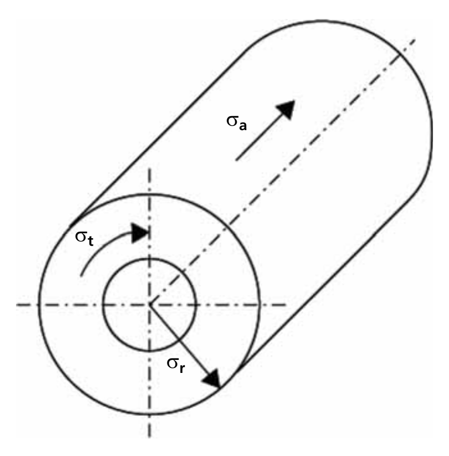


Figure 6.1 Stresses as function of the direction of their effects

The size of the respective stress can be calculated using the equations in chapter 7. The diagrams in appendix B are also aids for determining pressure load capacity.

6.1.1 Internal overpressure

An overload of a pressure pipe system due to internal overpressure results, especially in association with additional heat effects, to a continuous expansion of the pipe until it breaks.

The danger of an expansion arises as a result of too small wall thicknesses, in which an indiscriminate wall thickness increase is not justifiable. In the presence of heat expansion, a wall thickness enlargement also increases the reactive forces on the pipe fixed points. The engineer must ensure that the wall thickness is designed to meet requirements while the pipe remains elastic in response to any length changes that might arise. A sudden change in structural operating conditions due to internal pressure leads to pressure surges. The distinctive elasticity of the plastic pipe has the advantage that the extreme values of pressure waves are significantly lower than in steel pipes. Despite this fact, pipe systems operated by pumps or containing rapidly closing shut-off valves must be tested for any foreseeable effects of pressure surges.

6.1.2 Internal underpressure and/or external overpressure

Thin-walled pipes can dent as a result of internal underpressure or external overpressure, which is to say that they can lose their circular shape. To guard against possible instability, the critical dent pressure of a pipe must be calculated in relation to the standard dimension ratio. The critical dent pressure (ρ_{crit}) must display a safety factor SF = 2.0 against underpressure (according to ATV A 127, a safety factor of 2.0 to 2.5 is to be incorporated). In professional literature, the denotation "N" is used to designate the safety factor (SF).

6.2 Stress due to pipe deflection

Usually, deflection occurs in a pipe length as a result of the filled pipe's dead weight, including the weights of valves. The flexural stress resulting from a bend depends on the weight and span of the pipe between two support points.

In establishing support distances (LD) in compliance with appendix B4, the flexural stresses are so small that no overload or strain on the outer surface can occur. It must be noted that support distances have to be reduced when other components (e.g. valves) are present, or else additional support has to be provided. Especially notable are the significantly higher flexural stresses created by deformation of pipe branches and bends in connection with changes in direction.

Experienced has shown that, depending on the installation temperature and the standard dimension ratio, the bending of pipe strings that might predominantly occur in buried installations does not have any effect on the service life and operational reliability of the pipe. Temperature loads in a plastic pipe system affect strength values. Varying temperature loads can produce heat stresses if pipe expansion is restricted or prevented. Heat stresses are also created by temperature differences between the inner and outer wall of the pipe.

The stresses created by constricted conditions (e.g. impeded thermal expansion between two fixed points) are absorbed by the visco-elastic behaviour of the plastic pipe until a tension/expansion equilibrium is created. This process is also termed relaxation. Critical operating conditions arise when varying loads are involved, and the periods of high temperature grow longer than the periods of low temperature. In particular, tensile stresses with long-term effects can, after frequent load changes, result in fatigue fractures. Stress peaks occur when an initial temperature variation affects an installation condition. If the temperature level remains nearly constant over a longer period, the heat stresses are reduced by relaxation to level = 0.50% of the maximum value. Heat stress generated by a varying thermal load and tensile stress having a long-term relaxing effect can be calculated according to the equations in chapter 7.

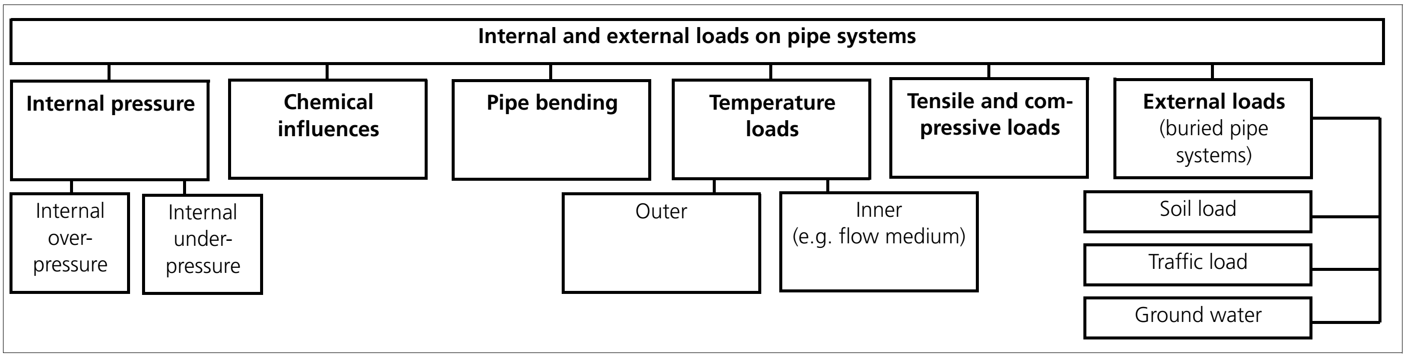


Figure 6.2 Internal and external loads on pipe systems

6.3 Tensile and compressive loads

As a result of differing thermal expansions in the inner and outer wall of a pipe, compressive stresses develop on the warmer side and tensile stresses on the colder side. At the same time, these stresses interact with the internal pressure. Stress values can be calculated using the equations in chapter 7. Compressive and tensile stresses do not only arise in connection with constricted thermal expansion but also due to the internal pressure itself. In particular, length changes related to short-term stress peaks can be observed in pressure tests involving increased internal pressure. It should also be noted that the effects of notches in the pipe wall are significantly strengthened by tensile loads.

6.4 Loads on buried pipe systems

6.4.1 Soil load

The bearing capacity of buried plastic pipes depends on the combined effects of pipe and soil. The top of the pipe is pressed down under soil load and the sides of the pipe are pushed out into the surrounding soil.
The reaction pressure that a lateral force exercises on the pipe causes a large cross-section deformation (support effect). The form of the trench, the nature of the pipe embedding and the backfill for the trench substantially determine the bearing capacity and stability of a buried plastic pipe system. The load must be evenly spread over the entire pipe length. It is also necessary to design pipe brackets that eliminate longitudinal bending and point loading. The acceptable installation depth (i.e. the bearable soil load (ρ_E)) is calculated using the following equation:

$$p_E = \gamma_B \cdot h$$

Equation 6.1

p_E = external soil pressure (kN/m^2)
γ_B = specific weight of the soil (kN/m^3)
(soil groups 1-3 -> $\gamma_B = 20$)
h = height of the soil layer above the top of the pipe

The acceptable installation depth (i.e. the bearable soil load) essentially depends on:

- pipe wall thickness
- pipe and soil stiffness
- form of the trench
- pipe embedding and trench backfill

6.4.2 Traffic load

Pressure dispersals resulting from traffic loads due to road and rail transport are assumed to be an evenly distributed surface load (ρ = surface load). The soil stress (ρ_{soil}) resulting from traffic loads is calculated in the following equation:

$$p_{soil} = a_F \cdot p_F$$

Equation 6.2

p_{soil} = soil stress (kN/m2) (acc. to ATV A 127, there designated "ρ")
a_F = correction factor for road-traffic loads (-)
p_F = soil stress resulting from traffic loads (kN/m^2)
(acc. to ATV A 127)

The stresses derived from the above-indicated equation are multiplied by a shock factor (φ), which takes the nature of traffic load into consideration.
Generally, the following shock factors are employed:

$$\left.\begin{array}{l}1.2 \text{ for SLW 60}\\ 1.4 \text{ for SLW 30}\\ 1.5 \text{ for SLW 12}\end{array}\right\}\text{ road traffic}$$

Inserting the calculated stresses and corresponding shock factors in the following equation 6.3 yields the actual effective traffic load.

$$p_V = \varphi \cdot p_{soil}$$

Equation 6.3

p_{soil} = soil stress (kN/m^2) (acc. to ATV A 127)
φ = shock factor for road-traffic loads (-)
p_v = soil stress resulting from traffic loads (kN/m^2)
(acc. to ATV A 127)

For pipes under railways, the following applies:
$\varphi = 1.4 - (0.1 \cdot (H - 0.5)) \geq 1$
With burial depth ≥ 4.00 m, general experience indicates that all stress differences between dead soil load and percussive traffic load completely disappear. With diminishing burial depths, the influence of the traffic load above soil load grows larger. The minimum height of the soil layer H_{min} for railway traffic loads is:

$$H_{min} = 1{,}50\ m$$

Equation 6.4

Under certain conditions, a minimum soil layer $H_{min} \leq 1.50$ m make it necessary to invoke special measures (e.g. use of protective pipe). The guidelines from Bahn AG are to be observed when manufacturing railway crossings. The vertical aggregate stress on buried pipes is composed of both soil and traffic loads. The horizontal stresses produced by traffic load can be ignored.

6.4.3 Ground water

Buried pipes can be exposed to external overpressure (this especially applies to areas with high ground-water tables). Similarly, a pipe encased in concrete, if only for a short time, is subject to an external pressure. A dent resistance test is required for buried pipe systems that are burdened by additional external pressure.
The effects of the external pressure load correspond to the hydrostatic pressure on the pipe axis.

$$p_w = \gamma_W \cdot \left(h_W + \frac{d_e}{2}\right)$$

Equation 6.5

p_W = external water pressure (bar)
γ_W = specific weight of the fluid (for water = 1.00) (kN/m^3)
h_W = height of the water column above the top of the pipe

The critical dent pressure (ρ_K) of a circular PE pipe as a result of water pressure is:

$$p_k = \frac{2 \cdot E_{C_R}}{1-\mu^2} \cdot \left(\frac{e}{d_e}\right)^3 \cdot 10$$

Equation 6.6

E_{CR} = creep modulus for the pipe material as a factor of temperature and load period (N/mm^2)
e = pipe wall thickness (mm)
d_e = outside diameter of the pipe (mm)
p_k = critical dent pressure (bar)
μ = transverse contraction value (for PE μ = 0.38-0.40) (-)

The safety factor (SF ≥ 2.0) usually used in the stability test (according to ATV A 127, a security factor designated there as "N" of 2.0 to 2.5 is to be taken into account) makes it necessary to undertake the following verification:

$$p_{W_{acc}} \leq \frac{p_k}{SF}$$

Equation 6.7

$p_{W\ acc}$ = acceptable external water pressure (bar)
p = critical dent pressure (bar)
SF = safety factor (-)

Note:
The soil surrounding a buried pipe has a supporting effect. It is therefore possible to derive support factors that enable the critical and, consequently, the acceptable external pressures to be increased. Technical literature provides the support factor values indicated in table 6.1.

Nominal pressure	Support factors fsup (-)	
(bar)	with compaction	without compaction
SDR 17	2.3	1
SDR 11	1.2	1

Table 6.1 Support factors for buried pipe systems

Appendix B11 can be consulted to roughly estimate the external pressure stability.

Example applying appendix B11
Invoking three examples, we can clarify the use of appendix B11 for potential pressure loads created by external overpressure or internal underpressure.

Case 1: External overpressure alone
Operating conditions:
Material: PE100, SDR 11
Operating temperature: 25°C
Internal underpressure (p_u) 0 bar (no underpressure)

Result:
Maximum pressure load ($p_{ex\ tot}$) from external overpressure (p_{ex}) (maximum height of the water column (h_w) above the top of the pipe) and no underpressure (p_u) in the pipe system:

Read from appendix B11:
$p_{ex\ tot}$ = 1.0 bar à 10 mWs
-> $p_{ex\ tot}$ = $p_{ex} + p_u$
-> p_{ex} = $p_{ex\ tot} - p_u$ = 1.0 bar - 0 bar = 1.0 bar
à p_{ex} = $p_{ex\ tot}$ = 1.0 bar

Case 2: Internal underpressure alone
Operating conditions:
Material: PE100, SDR 11
Operating temperature (T_{O1}): 25°C
Operating temperature (T_{O2}): 50°C
External over pressure (p_{ex}): 0 bar (no external overpressure)

Result:
Maximum pressure load (pex tot) from internal underpressure (pu) and no outside overpressure (pex):

Read from appendix B11:
for T_{O1} = $p_{ex\ tot1}$ = 1.0 bar
for T_{O2} = $p_{ex\ tot2}$ = 0.6 bar

For T_{O1}, the following holds:
-> $p_{ex\ tot1}$ = $p_{ex} + p_u$
-> p_u = $p_{ex\ tot1}$ - pex = 1.0 bar - 0 bar = 1.0 bar
-> p = $p_{ex\ tot1}$ = 1.0 bar
-> The selected pipe system is vacuum stable.

For T_{O2}, the following holds:
-> $p_{ex\ tot2}$ = $p_{ex} + p_u$
-> p = $p_{ex\ tot2}$ - p = 0.5 bar - 0 bar = 0.5 bar
-> p_u = p $_{tot2}$ = 0.6 bar
-> p_{atm} = 1 bar ; $p_{abs} = p_{atm} - p_u$ = 1 bar - 0.6 bar
= 0.4 bar absolute pressure
-> The selected pipe system is not vacuum stable under these operatingconditions, as $p_{u\ max}$ = 0.6 bar!

Case 3: Internal underpressure and external overpressure
Operating conditions:
Material: PE100, SDR 11
Operating temperature (T_{O1}): 25°C
Operating temperature (T_{O2}): 50°C
Maximum water column above the top of the pipe = p_{ex}: 7 m
Maximum underpressure (p_u) in pipe system: 0.2 bar

Result:
Maximum pressure load ($p_{ex\ tot}$) from external overpressure (p_{ex}) (maximum height of the water column (h_w) above the top of the pipe) and internal underpressure (p_u) in the pipe system:

Read from appendix B11:
for T_{O1} = p $_{tot1}$= 1.0 bar
for T_{O2} = p $_{tot2}$= 0.6 bar

For T_{O1}, the following holds:
-> p $_{tot}$ = $p_{ex} + p_u$
-> $p_{ex\ tot}$ = $p_{ex} + p_u$ = 0.7 bar + 0.2 bar = 0.9 bar
-> $p_{ex\ tot} = p_{ex\ tot\ 1}$
-> selected pipe is suitable!

For T_{O2} , the following holds:
-> $p_{ex\ tot}$ = $p_{ex} + p_u$
-> $p_{ex\ tot}$ = $p_{ex} + p_u$ = 0.7 bar + 0.2 bar = 0.9 bar
-> p_{ex} = $p_{ex\ tot2}$
-> Since $p_{ex\ tot} > p_{ex\ tot2}$, the total pressure load for the pipe system selected in the example is too large, which means that the selected pipe is unsuitable for this load.

T_O = operating temperature (°C)
T_{O1}, T_{O2} = selected operating temperature (°C)
p_{ex} = external over pressure (bar)
p_{abs} = absolute pressure (bar)
p_{atm} = atmospheric pressure ≈ 1 bar (bar)
$p_{ex\ max}$ = maximum external overpressure (bar)
p_u = internal underpressure (bar)
$p_{u\ max}$ = maximum internal underpressure (bar)
$p_{ex\ tot}$ = pressure difference between external overpressure and internal underpressure (bar)
$p_{ex\ tot1}$ = pressure load read from appendix B11 for t_{O1} (bar)
$p_{ex\ tot2}$ = pressure load read from appendix B11 for t_{O2} (bar)
h_w = height of the water column above the top of the pipe (m)

6.4.4 Superposition of loads

According to appendix B11, the simultaneous effects of soil pressure and external water pressure can reduce additional load values.
In practice, the superposition of several internal and external influences can occur and have adverse effects on a pipe system. This means that, besides external loads, internal loads arising from internal pressure and/or impeded thermal expansion can affect the pipe system. In addition, buoyancy in ground water can cause flexural stress along the pipe axis. The multiplicity of superposed loads requires careful and extensive planning of buried plastic pipe systems.

6.4.5 Structural analysis

Buried pipe systems must be regarded as special cases on account of their external loads.
They always require a differentiated analysis based on the installation guideline ATV A127 (on the standards NEN 3650, NEN 3651 and NPR

3559 in the Netherlands). Most equations and data on the preceding pages are established on the basis of this ATV guideline. A generalisation of the calculation methods is not possible due to the extent of the factors involved, making it necessary to abandon any simple overview of the equations.

6.5 Causes of length change

Plastic pipe systems are subject to discernible length changes even under small temperature variations on account of their high thermal length expansion coefficient (α_ϑ). As a result, the pipe system is constantly in motion in order to compensate for any temperature differences that arise. Length changes and associated linear expansions in pressure pipe systems mostly occur due to the superposition of several influential factors. The largest role in this regard is played by the additional occurrence of internal pressure loads.

6.5.1 Length change due to internal pressure load
Consideration must be given to pressure tests on pipe systems in which the test pressure can be 1.5 times larger than the nominal pressure. Test and/or operating pressures create axial stresses in the pipe that can result in longitudinal deformation on account of the low creep modulus of thermoplastics. The actual length change will often turn out to be smaller than the mathematically calculated one, since the expansion of the pipe system is impeded by friction. This difference is, however, irrelevant to the mathematical analysis of length changes and their effects.

6.5.2 Length change due to chemical effects
Besides the frequently mentioned good to very good resistance of polyolefin to a large number of chemicals, there are cases when chemical interaction is to be anticipated. In such cases, the appropriateness of the pipe material should be tested on the expected chemicals to be transported early in the planning stage. Various chemicals can cause length changes in pipe systems. Under certain circumstances, the chemicals being used can instigate swelling of the pipe or fitting. In such cases, the pipe wall absorbs more or less of the fluid contacting the pipe wall and consequently increases in volume. This expansion occurs both in a horizontal and in a radial direction to the pipe axis. The action of chemical compounds can, under certain conditions, result in reactions that have a detrimental effect on operating temperature. These temperature changes can subsequently produce thermal length changes that are unwanted and harmful to the pipe system.

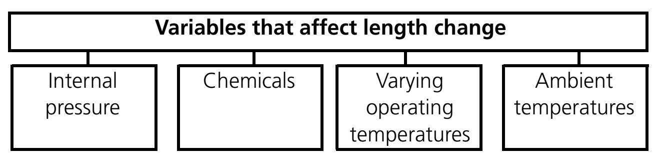


Figure 6.3Variables that affect length change

6.5.3 Length change due to varying operating temperatures
In only considering the effects of operating temperature, it is possible to detect that the condition of the pipe changes after initial use in accordance with the operating temperature involved.
Decisive for the size of the length change is the temperature difference ($\Delta\vartheta$) that comes into effect. It is therefore advisable to test the effects of the length change at various operating temperatures at least once. After initial operation, a check should be made to see if the shifting of individual pipe lengths has damaged or might damage the pipe fixed points.

6.5.4 Length change due to ambient temperatures
Not only temperature differences of the medium but also outside temperature differences caused by changes between day and night as well as summer and winder periods are partly associated with large length changes. In particular, empty pipe systems exposed to solar radiation or the effects of frost must contain sufficiently designed compensation elements. The risk potential results from high flexural stresses in expansion bends and large forces on clamp positions (pipe fixed points).

6.6 Compensation for length changes

Plastic pipe systems are generally installed so that a compensation device absorbs any length change. There are also various design options, which will be dealt with in the following chapters.

6.6.1 Elbows
Usually, the site-specific pipe layout can be segmented by a given fixed-point design enabling length changes to be absorbed by pipe strings running at right angles to the direction of expansion.
This requires the smallest expenditure and the pipe system remains, in itself, closed.
The compensation pipe lengths created by this installation method have L, Z or U forms, or are geometrically interconnected with each other in the indicated forms.
Consideration has to be given to the fact that length changes in one pipe string lead to bends in others.
Since the resulting flexural stresses are transmitted to the expansion bend, it is recommended that these do not exceed the minimum length calculated in appendices B5 to B8.
The mathematical determination of expansion bends as compensation for length changes will be discussed in detail in chapters 7.2.10.

6.6.2 Compensators
If linear compensation by means of expansion bends is not or only partly possible, compensators must be incorporated in the system. These are also required at connection points with smaller load capacities, such as pump and tank supports.
In addition, compensators serve to reduce vibrations and their transmission to building structures. The design and construction of compensators is based on operating pressure and temperature.

- Axial compensators
Axial compensators are predominantly used to absorb length changes along the pipe axis. They can only absorb longitudinal forces by using tension bars, but not any transverse forces.

- Lateral compensators
Lateral compensators serve to absorb movement in both axial and transverse directions to the pipe axis. Since tension rods are involved in their construction, they constitute a force-locking element in the axial direction.

- Angular compensators
Angular compensators are also called lateral expansion joints. They provide suitable compensation for large length changes in both level and three-dimensional pipe systems. A length change is compensated in the expansion joint by bending pipe sections.

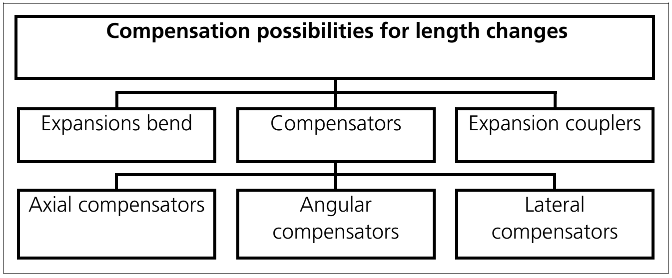


Figure 6.4 Length change compensation

- Forces in pipe lengths with compensators

Each length change in pipe systems generates a resistance of which the size is influenced by the nature of the compensation elements. The smaller that this resistance is, the smaller the reaction forces are and the larger the length change (Δl). The length change of the pipe causes the compensator to be pressed together or deformed and exercises, as a result, a reaction force.

The reaction force (= fixed point load) is composed of the deformation resistance of the compensator and the longitudinal force produced by the internal pressure, based on the effective cross-sectional area of the compensator.

The possibility cannot be excluded that the load on the fixed point is made larger by incorporating an compensator than it would be using expansion bends. In planning fixed point constructions, special attention should be paid to this fact.

- General remarks on compensators

The following rules need to be followed when making use of compensators:

- To function effectively, compensators must be mounted between two fixed points.
- The distance from one guide bracket (guide saddle) should not be any larger than 3x the pipe diameter.
- Only one compensator can be fitted between two fixed points.

6.6.3 Expansion couplers

Expansion couplers are suitable for absorbing axial length changes. Moreover, expansion couplers are only to be used in pipe systems in which no load produced by underpressure is to be expected (leakage in the sealing part of the coupler). If abrasive media are being transported (e.g. hydraulic transport of solids such as quartz sand water mixtures), Akatherm will certainly not be allowed to employ expansion couplers. Details on function, specifications and areas of application for expansion couplers can be found in chapter 8. By arranging guide brackets (guide saddles) in the immediate proximity of couplers, care needs to be taken to prevent the pipe from kinking on the side. The expansion coupler is not longitudinally force-locked and must also be installed between two fixed points. The resulting load on fixed points is smaller than the fixed-point that occur when compensators are used. A typical application for expansion couplers involves linear compensation in a rigid connecting piece between or more tanks.

6.7 Brackets

Brackets, also called pipe bearings, pipe saddles or pipe fixings, have the task of safely transferring all the loads arising in an pipe system to the building structure or infrastructure. Pre-requisite for the combined effects of pipes and brackets is the functional construction and design of the fixing elements. Examples of various arrangements of brackets in a pipe system are presented in figure 7.13.

6.7.1 Sliding and hanging brackets

Sliding and hanging brackets (sliding and hanging bracket saddles) can only absorb vertical forces and will only provide limited resistance to any operating movement. In incorporating sliding and hanging brackets, care must be taken that both longitudinal and a lateral movement of the pipe is given some play. The nature of this type of fixing is extremely susceptible to vibration, so their use in pipe systems powered by pumps is not recommended or only permissible along with guide brackets (guide saddles).

6.7.2 Guide brackets

Guide brackets (guide saddles) have to prevent any lateral deflection of the pipe. Due to their construction, they are therefore able to absorb transverse forces. The incorporation of guide brackets ensures that a pipe string cannot kink as a result of axial restraint.

6.7.3 Criteria for using brackets

The most important criteria for the correct application of brackets in a plastic pipe system are:

- If possible, pipes should be equipped at the bracket points with saddles. If there is no provision for the sliding of pipes in the saddles, plastic or rubber inserts can be used. The pipe may, however, not be crimped at the fixed point.
- If the pipe is to have the possibility of moving freely and uninhibitedly in brackets (saddles), the inside diameter of the bracket must be larger than the outside diameter of the pipe.
- Brackets may not be sharp-edged or linear. Point supports are also not acceptable.
- Pipes with large diameters are frequently equipped with saddle shaped supports. The angle of contact of the pipe must be at least 90°. At the same time, it must ensure suitable lift protection.
- The expansion of the pipe string must not be impeded by the bracket construction. The structure of the sliding surfaces must be corrosion resistant and offer sufficient room for shifting. Under certain circumstances, a final limit is provided.
- In a pipe installation without linear compensation (axially constricted), the acceptable support intervals (L_S) is, according to appendix B4, comparable with the critical buckling length $L_K = L_F$ (guide distance) indicated in appendix B10.

The smallest value indicated in this comparison is to be used as the actual value, which is $L_{act} = L_x$ (with $L_x \leq f\ (L_s, L_K, L_F)$). The acceptable fixing distance is:

$$L_{act} \leq L_K \text{ by which } L_K \leq L_F < L_A$$

Equation 6.8

This especially applies to pipes of small diameter.

- At positions in which the bracket distances must have very large designs for structural reasons, additional or movable supports (e.g. installation rails) must be provided. A support also serves to stabilise small pipes and prevent larger flexural deflections in pipe systems under constantly high operating temperatures. The support is connected to the pipe by means of a strap. Care must also be taken to ensure that , despite the additional supports, unimpeded sliding in brackets and/or expansion couplings can occur.
- If heat expansion gives rise to the danger of the pipe being lifted off its supports, or if vertically hanging brackets are attached to vertically inclined pipe sections, the inclusion of additional spring elements can be required (constant support).
- Sliding and hanging brackets (sliding and hanging bracket saddles) are provided if movement might occur in any direction. The pipe supported in this manner is however very susceptible to damage from vibration and must have a few intermediate brackets for cushioning effect.
- Concrete applications for sliding and hanging brackets (sliding and hanging bracket saddles) occur as fixed points involving expansion bends. Their design ensures that the acceptable support distances are not exceeded even in cases of large expansion bends.
- Radial guide brackets (guide saddles) are predominantly used with inclined pipes. They should be constructed In such a way that movements along the pipe axis are possible while the pipe axis is prevented from kinking. In addition, reaction forces due to vibrations of the radial guide brackets can be dissipated.

6.7.4 Fixed points

Fixed points will prevent shifting or movement of the pipe in any direction. They also serve to absorb reaction forces (e.g. when compensators or expansion couplers are used).

If a pipe system is constructed so that linear compensation cannot occur (axially constricted), the fixed-point design must be given special attention. The mathematical calculation of loads on fixed points will be discussed in chapter 7.2.11.

6.7.5 Principles for the layout and construction of fixed points

- Fixed points are to be arranged so that direction changes in the pipe route can be used to absorb length changes.
- They are also to be designed in considering all the loads that might arise. In addition to reaction forces from friction at bracket contact points and deformation of bends, large forces are produced by fixed restraints of pipe lengths.
- The pipe must have the appropriate retainer rings to transfer the forces to the construction of the fixed point. Insufficient consideration of the restraint of the pipe in the bracket alone will, in many cases, cause deformation of the pipe cross section or damage to the pipe surface.
- Fixing pipe systems at fixed points should, if possible, be done at low ambient temperatures, giving rise to predominantly compressive stresses when heated (operating state).
- If flange connections occur in pipe lengths between fixed points, tensile stresses can cause the joint pre-tension forces to decrease, resulting in leakage at the flange connections.
- In inclining pipe segments, fixed points are employed to absorb dead weight and dynamic loads. The design has to ensure that vertical length changes do not produce any unacceptable tensile loads on the horizontal connections.

6.7.6 Valve mounting

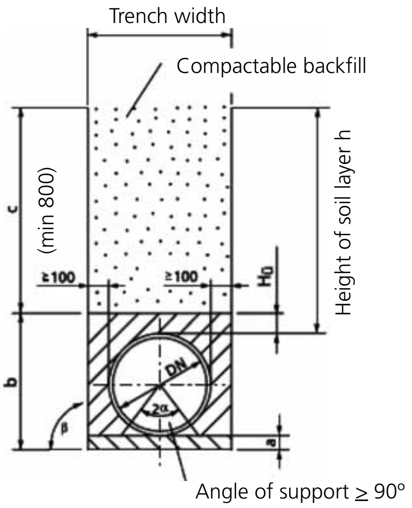
Locations in which valves or other heavy equipment encumber the pipe system have to be provided with an additional support structure. Supporting valves not only serves to bear weight but also prevents the transfer of large actuating forces to the pipe system.
The design features must be arranged to enable replacement of the valves without simultaneous disassembly of the entire fixing. If the valve mount corresponds to a fixed point, consideration must be given to the consequences of the restricted length change.

6.7.7 Protective measures

Protective measures for above ground pipe systems outside buildings (e.g. on pipe bridges) include insulation against loss of heat or cooling, concomitant heating and UV light blinding. Protected pipes are no longer exposed to extreme ambient temperatures that can result in such effects as a reduction in length change. In establishing the bracket distances in accordance with appendix A8 to A15, B4 and B10, it should be noted that the dead weight of the insulation will cause increased deflection. Protective measures can also be used to limit maximum pipe wall temperatures and therefore broaden the range of internal pressure loads for which the pipes are suitable. DVS 2210 Part 1 provides the following information on the UV stability of PE:
"Thermoplastic pipes treated with stabilising additives can be used in the open without any lasting effects from ultraviolet radiation (UV rays). Despite coating the thermoplastic with lightfast pigments, longer exposure to intensive UV light can cause discolouration (bleaching of the original colour). Reduced impact resistance is also not to be excluded."

6.8 Construction and installation of buried pipe systems (figure 6.5)

Following is based on German directions.



A = Pipe bed (in pipe zone)
100 mm for normal soil composition
150 mm on rocks or hard soils

B = Pipe zone with height of soil layer H_o

C= Backfill with a soil layer over the pipe zone that has a height of at least 800 mm

▨ (stone-free sand, compacted)

Figure 6.5 Design of the trench

The height of the soil layer over the pipe is:
H_{min} (*) + H_{max} = mathematical calculation for the individual case in accordance with ATV guideline A 127

(*) Note on H_{min}:
The KRV installation guideline for "pressure pipes" recommends that, in designing pipe trenches, all pipe elements are to be placed at a frost-free depth. Depending on the climate zone, the minimum height of the soil layer over the pipe must lie between 0.80 and 1.80 m. The standards for trench design are NEN-EN 1610, DIN 4124 and DIN 19630.

Trench bottom - Area a
The form and consistency of the trench bottom affects the mechanical properties of thermoplastic pipes. The already present or prepared bed must consist of stone-free sand and be easy to compact using appropriate equipment. The pipe must be laid so that a suitable supporting surface with an angle of at least 90° is formed. The depth of the trench can be calculated using equation 6.9, which is frequently employed in practice:

$$H_{Tr} = minimum\ 100\ mm + \frac{DN}{10}$$

Equation 6.9

H_{Tr} = depth of the trench (mm)
DN = Nominal diameter of the pipe (mm)

The above-cited equation 6.9 is given the same form in NEN-EN 1610. NEN-EN 1610 provides the following minimum values that, unless otherwise indicated, should not be exceeded:
- normal soil composition -> 100 mm
- rocks or hard soils -> 150 mm

Pipe embedding - Area b

The fill for the embedding of pipe systems must be stone-free soil, sand or similar material that must be capable of proper soil compaction. The embedding procedure significantly determines the soil pressure and soil-load distribution, as well as the formation of a stress-relieving, lateral soil pressure on the pipe.

The height of the embedding layer over the pipe (H_O) is:

H_0 = min. 150 mm over the top of the pipe and 100 mm over connecting elements (as stated in NEN-EN 1610)

Backfill - Area c

The backfilling and compacting of the trench occurs in layers. Soil types and materials that can result in settling at a later time may not be used to backfill the trench (e.g. ash, slag, stones). The compression ratio of backfill material is measure in %Proctor ($\%D_{pr}$). The use of heavy compacting or compression equipment for soil compaction is not permitted when the soil layer over the pipe is < 1.0 m.

6.8.1 Construction principles

The design (i.e. the form of the trench), the backfill and the corresponding compaction of materials have important effects on the service life of plastic pipe systems.

The following construction principles should therefore be observed:
- The pipe trench is shaped so that all pipe parts are covered by the prescribed soil layer.
- In laying plastic pipes on the prepared trench bottom and in subsequently embedding them, stones must be prevented from contacting the plastic pipe (danger of notching that leads to cracking).
- In rocky or stony subsoil, the trench bottom is to be excavated 0.15 m deeper and the additional excavation filled by a stone-free support layer.
- Sand and fine gravel (grit size <20 mm) are the most suitable materials for embedding pipes and compacting the pipe zone.
- All soil types occurring in nature are classified in DIN 18196 "Soil classification for construction purposes and methods of recognising soil groups". Soils are divided into:
  - Group 1: non-cohesive coarse soils (sandy, gritty soils)
  - Group 2: cohesive, fine soils (coarse clay, clay)
  - Group 3: cohesive, fine and coarse mixed soils (cohesive sandy soils, gritty soils, cohesive stony weathered soils).
- The compactability of individual soils and, consequently, the quality of the compaction depend on the granulometric composition, the grain shape and water content. The method of compaction with regard to the equipment used is shown in table 6.2.
- Concrete or clay bar must, in certain circumstances, be incorporated in slopes in order to prevent the sandy pipe bed from being washed away. In some cases, drainage must be provided.
- In the case of bearing capacity changes of the trench bottom due to differing soil layers, a sufficiently long fine-gravel or sand fill is applied at the transitions.

The following instructions sheets are important for pipe trench design:
- DIN 4124 "Excavations and trenches"
- Din 19630 "Guidelines for the construction of water pipes: DVGW Technical Regulations"
- NEN-EN 1610 "Laying and testing drainage pipes and canals: Dutch Version EN 1610:1997"

Type of equipment			Soil group								
		Service weight (kg)	I Coarse (non-cohesive)			II Fine (cohesive)			III Mixed grained (cohesive)		
			Appropriate	Layer height (cm)	Number Trans.	Appropriate	Layer height (cm)	Number Trans.	Appropriate	Layer height (cm)	Number Trans.
1. Light compacting equipment (predominantly for the pipe zone)											
Tamper	**light**	≤ 25	+	≤ 15	2 - 4	+	≤ 10	2 - 4	+	≤ 15	2 - 4
Frogrammer	**medium**	25 - 60	+	20 - 40	2 - 4	+	10 - 30	2 - 4	+	15 - 30	3 - 4
	light	≤ 100	o	20 - 30	3 - 4	+	20 - 30	3 - 5	+	15 - 25	3 - 5
Vibrating plate	**light**	≤ 100	+	≤ 20	3 - 5	-	-	-	o	≤ 15	4 - 6
Vibrating roller	**medium**	100 - 300	+	20 - 30	3 - 5	-	-	-	o	15 - 25	4 - 6
	light	≤ 600	+	20 - 30	4 - 6	-	-	-	o	15 - 25	5 - 6
2. Medium and heavy compacting equipment (above the pipe zone)											
Tamper	**medium**	25 - 60	+	20 - 40	2 - 4	+	10 - 30	2 - 4	+	15 - 30	2 - 4
	heavy	60 - 200	+	40 - 50	2 - 4	+	20 - 30	2 - 4	+	20 - 40	2 - 4
Frogrammer	**medium**	100 - 500	o	20 - 40	3 - 4	+	20 - 30	3 - 5	+	25 - 35	3 - 4
Vibrating plate	**heavy**	500	o	30 - 50	3 - 4	+	30 - 40	3 - 5	+	30 - 50	3 - 4
	medium	300 - 750	+	30 - 50	3 - 5	-	-	-	o	20 - 40	3 - 5
Vibrating roller	**heavy**	750	+	40 - 70	3 - 5	-	-	-	o	30 - 50	3 - 5
		600 - 8000	+	20 - 50	4 - 6	-	-	-	+	20 - 40	5 - 6

+ = recommended o = most suitable

Table 6.2 Type of compaction

* The above-stated data represents average performance data. In unfavourable conditions (e.g. high water content, sheet lining, the indicated layer heights have to be decreased, while they can be increased in especially favourable conditions. Precise values are only ascertained by means of trial compaction. If no trial compaction is run (except in cases involving steel and ductile iron pipes), only use the highest values for the layer heights indicated in the table.

6.8.2 Bending radius

Route direction changes can be followed by bending the pipe.
To avoid the risk of buckling and overstraining the outside surface, it is recommended that the minimum bending radius not be exceeded (table 6.3).

Material	Bending radius at various installation temperatures				
	ISO-S	SDR	0°C	10°C	20°C
PE100	8	17	50 x d_e	35 x d_e	20 x d_e
	5	11	50 x d_e	35 x d_e	20 x d_e

Table 6.3 Bending radius

Note to table 6.3:
The safety factor (SF) for the indicated SDR and ISO-S values of PE is 1.6. The bending radius at an installation temperature of 20°C were mathematically calculated. To calculate the bending radius at an installation temperature of 0°C, the mathematically calculated values for an installation temperature of 20°C were multiplied by a factor of 2.5. The bending radius at an installation temperature of 10°C were interpolated (mean values).

6.8.3 Building connections

When buried pipes connect to buildings, the possibility of settling has to be taken into account. The elastic plastic pipe, due to the deformation capacity zone (figure 6.6) over the length DZ (elbow length) ensures that no overload can occur in the area of settlement.

6.9 Principles of constructing and installing concrete-encased pipe systems

Plastic pipes encased in concrete after installation represent a special case. Their handling in connection with the technical application guidelines in for pressure pipes in this manual is therefore limited to important or critical details. The instructions may be applied to other similar circumstances.

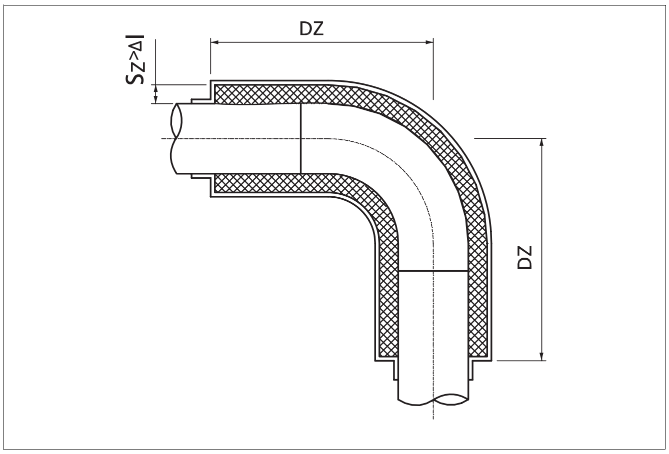


Figure 6.6 Expansion zones in pipe bends

6.9.1 Behaviour of pipe systems under temperature loads

Once a pipe system is encased in concrete, no movement can any longer occur. A pipe system without linear compensation is created, meaning that increased heat stresses have to be taken into account. Since no friction-lock connection is formed between the straight pipe and surrounding concrete, the fittings constitute fixed points and are correspondingly subjected to stress. In installing pipe systems, measures need to be taken to limit the load on the fittings. Examples of such practices are described below.

6.9.2 Load on pipe bend

If extreme temperature differences can arise, pipe bends have to be protected against overstress. For this purpose, an expansion zone using deformable material is incorporated. The chosen thickness of the expansion cushions must be at least as large as Δl. The length of the expansion zone corresponds to the dimensions of the expansion bends in appendices B5 to B8.

6.9.3 Load on tee

Due to varying temperatures, fittings are subject to surface pressure. This adverse load concentrates on tee sections, as additional shear forces are created at outgoing connections.

If a load limiting element is placed directly beside the fitting, an electrofusion coupler is the most suitable connection piece. The longitudinal force (force on a fixed point) (F_{Fp}) remains equally large, but the deformation due to the significantly smaller Δl is clearly less. Another option for protection against overloading is the incorporation of an expansion zone (expansion cushion).

6.9.4 Fixing pipe systems

In comparison with brackets, the installation of a concrete-encased pipe system does not require any special measures. The fixing during installation only serves as float protection and is to be regarded as provisional attachment prior to encasement with concrete.

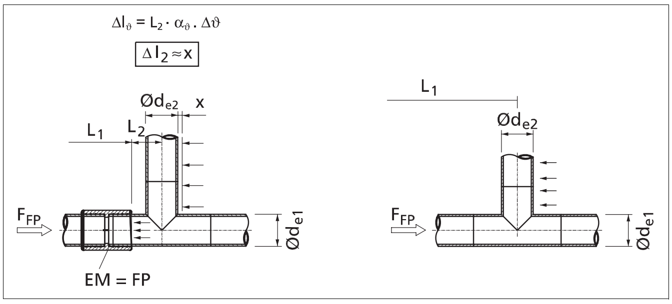


Figure 6.7 Shear and fixed-point forces on tees and 45° branches

6.10 Chapter summary

Internal pressure loads	Internal pressure loads create stresses in various directions. Radial stresses, axial stresses and tangential stresses can occur.
Internal overpressure	Internal overpressure can result in pipe expansion, especially under the effects of heat. Sudden changes in operation conditions can cause pressure surges.
Internal underpressure / external overpressure	Exposed to internal underpressure or external overpressure, a pipe will tend to buckle, which means it deviates for its ideal form (circular cross section). The critical buckle pressure should be calculated with regard to stability.
Pipe bending	Pipe bending is usually caused by the dead weight of the pipe and/or additionally incorporated valves and pipe fill. The relevant bracket distances (support distances) must therefore be determined and the suitable pipe brackets incorporated.
Temperature loads	Temperature loads have a very large effect on the mechanical properties of plastic pipe. Attention is first of all to be paid to the relatively large thermal length change.
Tensile and compressive stresses on the pipe wall	They are created during pipe manufacture due to differing cooling conditions. Compressive stresses arise in the outer wall of the pie (usually the first surface to cool) and tensile stresses on the warmer inner wall of the pipe.
Soil load	The soil layer on top of the pipe loads weight on the pipe and can cause it to deform. This load therefore has a significant effect on the pipe structure and the service life of the pipe.
Trench form, pipe embedding and backfill	Pipe trench design substantially influences the bearing capacity and stability of a pipe system, and therefore has a large influence on the service life of the system.
Traffic loads	Traffic loads are additional external loads that can affect the pipe system. They require special protective measures. If the prescribed minimum soil layer over the pipe is not maintained, protective pipes may have to be installed
Railway traffic loads (railway crossings)	The installation guidelines from ProRAil are important for installation under railways and railway facilities as well as for railway crossings.
Ground water	Areas having a high ground water table can load external overpressure on the pipe system. The same holds true for concrete-encased pipe systems, which are exposed to short-term heightened overpressures. Both cases require the calculation of dent resistance.
Length change	The length change of a pipe system is caused by varying operating temperatures, varying ambient temperatures or internal pressure loads. Frequently, several of these influences are superposed.
Compensation for length changes	The inclusion of elbows, expansion couplers or compensators can compensate for length changes.
Elbow	Elbows (expansion bends) absorb length changes by moving laterally perpendicular to the expansion direction. Depending on structural and spatial conditions, they can be U, L or Z shaped.
Compensators	Compensators are used if other compensation options cannot or can only be partially applied. The design depends on operating pressure and temperature. Axial, lateral and angular compensators are used.
Expansion couplers	Expansion couplers are predominantly employed in pressureless systems as connection elements and compensation for length changes.
Brackets	Brackets have the task of transferring the effective loads on the pipe system to the building structure or infrastructure.
Sliding and hanging brackets (sliding and hanging bracket sleeves)	They are only able to absorb vertical forces.
Guide brackets (Guide saddles)	They serve to absorb both vertical and horizontal forces.
Fixed points	Fixed points in association with suitable bracket concepts prevent shifting or movement of pipe systems.
Valve fixing	Valve fixings not only serve as support for valves but prevent the transfer of reaction forces.
Protective measures for above ground pipe systems	They are used to improve the insulation properties of pipe systems. The use of concomitant heating is necessary in many cases. Protective measure may also be taken against UV radiation.
Bending radius	In bending pipe, certain bending radius should not be exceeded (table 6.3).
Building connections	Connections of building can be exposed to settling, which can be compensated by creating deformable zones.
Concrete-encased pipe systems	Concrete-encased pipe systems function as a fixed restraint. Fittings behave in concrete as fixed points and are therefore also subject to the same stresses, which means that any heat stresses must be absorbed and compensated for in the pipe system.