Design of buried pipe system

A quick calculation guideline

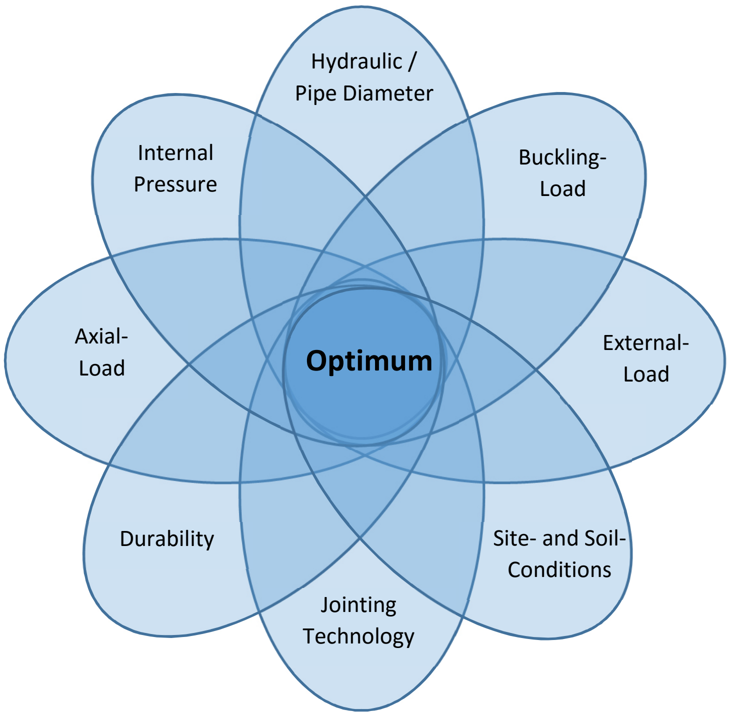
During the design phase of a new pipelines, civil-engineers often face problems and doubts of choosing the right and best pipe solution for the project. Several approaches are:

- Using of existing brochures of pipe producers and changing the project requirements until the project fits to the available pipe system.
- Using of international standards and choosing standard pipes and materials.
- Calculate the required optimum "tailor-made" pipe for the project requirements.

The first two choices make the design process quick, but it is not clear if the pipe is the optimum pipe or even if the pipe will fail. Especially when it is considered, that brochures are not neutral and that standards describe the minimum international consensus only.

So usually the design and determination of the pipe-system should follow a standardized calculation- and evaluation- process. After this procedure the decision can be made which system should be used to fit the requirements of the project best.

All topics what have to be considered before the choice for best pipe material and pipe system can be made.



In the following abstract the most important design-topics are explained and the main questions that have to be clarified are mentioned

1. Determination of pipe Diameter according hydraulic aspects

1. Dimensioning of the diameter – of course the inner diameter, because this is the hydraulic diameter of the pipe.

1.1 Definition of quantity and quality of fluid what has to be conveyed, so that viscosity and the content of the liquid is determined.

1.2 Consideration of Abrasion-behaviour of fluid/contents to different pipe materials

1.3 Clarification of the flow-characteristic of the fluid

1.4 What is the roughness of the inner pipe-surface before using and during operation, because it will affect the flow characteristic significantly

1.5 Which flow reduction factors must be considered for fittings, joints, valves and operation roughness

1.6 what other components in the line could affect the system roughness

$$Q = \frac{\pi \cdot {D_i}^2}{4} \cdot \left(-2 \cdot \log \cdot \left(\frac{2{,}51 \cdot \nu}{D_i \cdot \sqrt{2 \cdot g \cdot D_i \cdot J}} + \frac{k}{3{,}71 \cdot D_i}\right) \cdot \sqrt{2 \cdot g \cdot D_i \cdot J}\right)$$

Equation for volume flow capacity according DWA

Legend

Q = volume flow [m³/s]

Di = Inner Diameter [m]

ν = kinematic viscosity [m²/s] (sewage 12°C = 1,31 10^{-6})

k = K-value [mm], value depends from surface-roughness and considers
operation conditions incl. installed fittings and manholes,
for standard PE-Pipe-Systems k = 0,1

g = gravity acceleration [m/s²]

J = Linear Energy Slope [-]

Result: ***Inner Diameter and pipe material (of the inner layer)***

2. Design for internal pressure

2. The Internal pressure load defines the necessary minimum wall thickness

2.1 Clarification of necessary pressure capacity (according to pump design, hydrostatic situation, requested safety-factor)

2.2 Short term pressure load during testing (depending on test-requirements, the test-pressure load can also be decisive for design of the necessary wall thickness) The usual test pressure of a pressurized pipeline is 1,5 times the working pressure.

2.3 Water hammer, influenced by operating conditions, valve-systems, pipe flexibility and material characteristics have to always be considered for definition of the short term pressure load

2.4 Every load-case-combination has to be considered separately and in relation to the loading time

Determination of required wall thickness for internal pressure load:

$$e = \frac{p \cdot d_i}{\left(\frac{\sigma \cdot 20}{SF}\right) - p}$$

e = required wall thickness [mm]
for profiled wall structure $e_{4,5}$ (inner wall)
p = Inner pressure load [bar]
di = Inner Diameter [mm]
σ = Minimum Required Strength (MRS) [N/mm²]
SF = Safety Factor [-]; typical value for Polyethylene = 1,25

Consideration of water hammer:

$$p_{jouk} = \rho \cdot 10^{-5} \cdot a \cdot v_0$$

$$a = \sqrt{\frac{\frac{E_F}{\rho}}{1 + \frac{E_F}{E_P} \cdot \frac{d_m}{e}}}$$

$$=> \quad p_{jouk} = \rho \cdot 10^{-5} \cdot \sqrt{\frac{\frac{E_F}{\rho}}{1 + \frac{E_F}{E_P} \cdot \frac{d_m}{e}}} \cdot v_0$$

p_{jouk} = Maximum pressure [bar]
v_0 = Velocity of flow [m/s]
a = Pressure wave velocity [m/s]
ρ = Density of fluid [kg/m³]
μ = Poisson's ratio [-]
d_m = Mean diameter [mm]
e = Wall thickness [mm]
E_P = Flexural modulus Pipe Material under surge load [N/m²]
E_F = E-Modulus Fluid (Water = 2100 x 10^6 N/m²)

3. Design for buckling Load

3. Design of pipe wall structure according to buckling load under consideration of soil-support-effect
3.1 Clarification of water table outside pipe (culvert, ground water)
3.2 Clarification if buckling load by vacuum pressure inside pipe could occur (by operation conditions, e.g. sudden emptying of full filled pipe by hydrostatic situation)

Consideration of buckling load:

$$p_b = \frac{10 \cdot E_P}{4 \cdot SF \cdot (1 - \mu^2)} \cdot \frac{e}{r_m}$$

Legend

p_b	=	Buckling pressure capacity[bar]
E_P	=	Flexural modulus Pipe Material [N/mm²]
SF	=	Safety Factor [-]; typical value for stability considerations = 2,0
μ	=	Poisson's ratio [-]
e	=	Wall thickness [mm], for profiled wall structure equivalent wall thickness e_{equal} in reference to moment of inertia of pipe wall
r_m	=	Mean pipe radius [mm]

$$I = \frac{{e_{equ}}^3}{12}$$

e_{equ}	=	equivalent wall thickness e_{equal} [mm] ; defined for profiled wall only
I	=	Moment of inertia [mm⁴/mm]

The Moment of Inertia is in direct relation to pipe stiffness.
The pipe stiffness is calculated according ISO 9969 as follows:

$$S = \frac{E_P \cdot I}{dm^3} \cdot 10^3$$

S	=	Pipe Stiffness [kN/m²]
E_P	=	Flexural modulus Pipe Material [N/mm²]
I	=	Moment of inertia [mm⁴/mm]
d_m	=	Mean diameter [mm]

4. Design for external loads

4. Design of pipe stability for external loads
   - 4.1 What traffic load could appear
   - 4.2 What static load could appear
   - 4.3 What pipe stiffness is necessary to resist the loads ?
     It has to be considered that for flexible pipes (Polyethylene) most of the loads disappear after settlement-phase. The loads are taken then by the soil!

5. Design for axial loads

5. Pipe and Joint has to be designed for axial loads
   - 5.1 Axial loads by soil-movements and settlements
   - 5.2 Axial load by temperature of fluid
   - 5.3 Consideration of anchorage of profiled wall structure in the surrounding soil
   - 5.4 Load capacity of different jointing methods, typically a welding is a homogenous joint and able to transmit same load as the pipe itself

6. Consideration of installation and site conditions

6. Installation conditions
6.1 What equipment is available for installation and handling
6.2 Consideration of pipe weight and available length
6.3 What weather conditions could affect the installation and access to site

7. Consideration of soil conditions

7. What are the existing soil conditions, how will it affect the pipe design and how soil conditions can be improved
7.1 What type of soil
7.2 What density and compaction is existing
7.3 How the bedding can be prepared
7.4 What soil is available for backfilling and how the backfilled soil can be compacted best

8. Availability of pipe components

8. To design a complete pipe system, it is important that all needed components are available
8.1 Bends
8.2 Manholes
8.3 Reduction

8.4 Branches
8.5 House Connection
8.6 Connection to other pipe Materials, valves and pumps

9. Available jointing methods for pipe components

9. What jointing methods are available for the pipe material and pipe system
9.1 What are the jointing conditions? (temperature, water etc.)
9.2 A homogenously welded joint should be preferred instead of mechanical joints (100% water tight, no in- or exfiltration, axial load capacity same as pipe, no root penetration etc.)

10. Durability of pipe system

10. What is the durability of the pipe system and the pipe material itself under operating conditions?
10.1 For what life-time the pipeline has to be designed?
10.2 What factors affect the life time of the pipe /material and what are the maintenance-intervals (resistance for hydro-jet cleaning etc.
10.3 What is the considered safety in design ?
10.4 Is the complete pipeline homogenous or are there different materials with different durability (the weakest component determine the life-time, rubber sealing existing?)
10.5 Does Corrosion become a problem ? (leakage, stability, flow-characteristic etc.)
10.6 Is the pipeline easy to inspect? (inspection friendly inside surface)

11. Optimal Pipe Design

11. After all calculations you find the best suitable pipe:

- ➔ Inside Diameter
- ➔ Material
- ➔ Wall construction
- ➔ Jointing method
- ➔ Installation equipment

12. Supplier of Pipe System

12. How to find now the right supplier?
12.1 How to prepare a tender
12.2 Can the supplier only deliver a standard pipe or is he able to meet the requirements in the best way (optimum quality for the project with the lowest cost).

Example:
If a pipe with SN5 is required, why should a pipe of a standard stiffness classes like SN8 be bought?
The investment could be 40% less, if a pipe producer is offering a pipe made for the needs, so far the tender considers such tailor-made design.

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