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Article

Interaction between roadway and sewer/water pipes

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Abstract: Sewage pipes and drinking water pipes as well as all other pipes such as gas, district heating, electricity, internet, telephone, cable TV, etc. in densely populated areas are located in the road space. Over time, the traffic loads as well as the road structure can change. In addition, the materials of the pipelines are subject to ageing processes. The consequences of leaking drinking water and wastewater pipes that lie in the body of the road can have extremely negative effects. Firstly, the wastewater contains harmful substances that must not be allowed to enter the groundwater under any circumstances. Secondly, the leaking drinking water pipes, especially a water pipe burst, cause the soil mechanical changes in the subsoil and the traffic surface pavements and can cause immense damage in the road surface or in the road body itself.

Keywords: asphalt; drinking water pipe; pavement; road damage; sewage pipe; traffic load

1. Introduction

1.1. Position of pipes and cables in the street cross-section

The type, number, and distribution of the conduits present in a street cross-section are primarily dependent on local conditions such as street width, drainage systems, adjacent properties, and surrounding buildings. **Figure 1** [1] provides an overview of typical types of conduits in urban areas, encompassing both public and private lines.

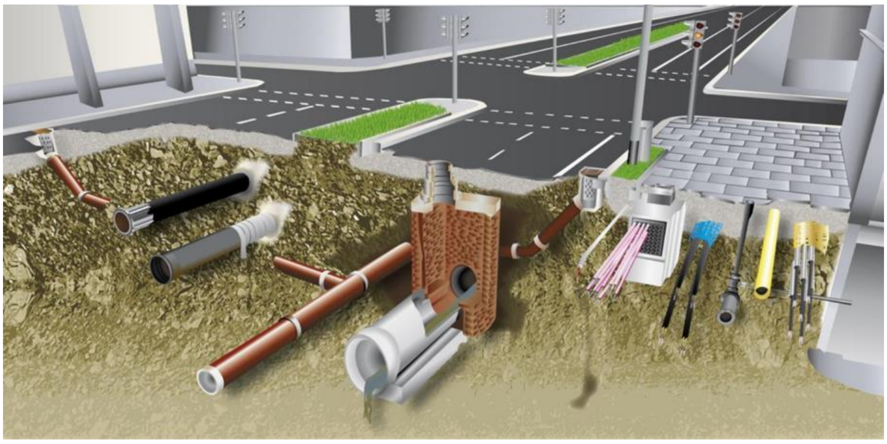


Figure 1. Pipelines in the street cross-section [1].

When cities decided to implement sewer systems, gas and water supply lines had often already been in place for several years, but these pipes were not always installed or documented according to uniform standards. During the construction of the deeper sewer lines, particularly in the narrow streets of old town areas, significant challenges arose. It was often impossible to maintain the required safety distance from the existing pipes, leading to ground movements that caused leaks in the joints or even breaks in the pipes. After the sewer systems were completed, it was often necessary to relocate sections of the gas and water lines. An extreme example of this situation from New York City in 1916 is shown in **Figure 2** [2].

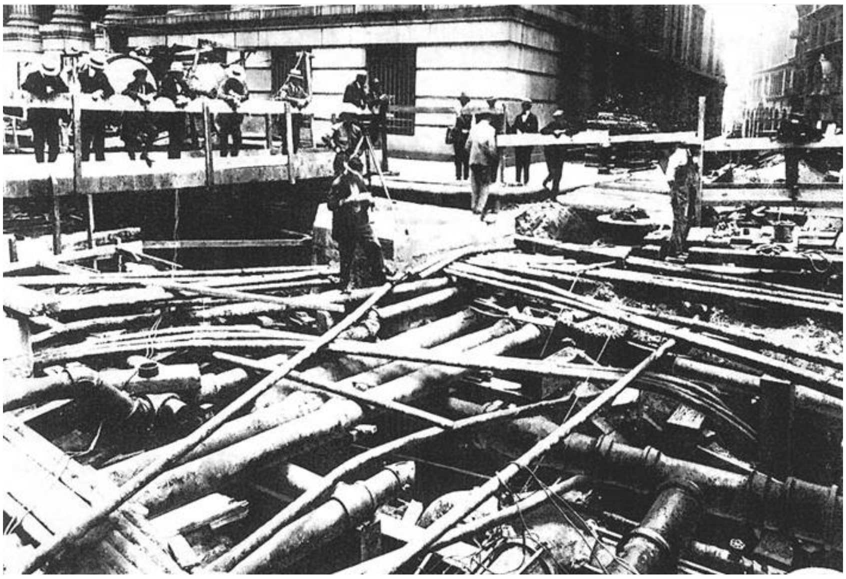


Figure 2. Underground pipes in New York around 1916 [2].

Figure 3 shows how underground pipes are laid today.

Figure 3. How underground pipes are laid today [3].

The Position of the supply lines in the street cross-section according to German standard DIN 1998 shows **Figure 4** [4].

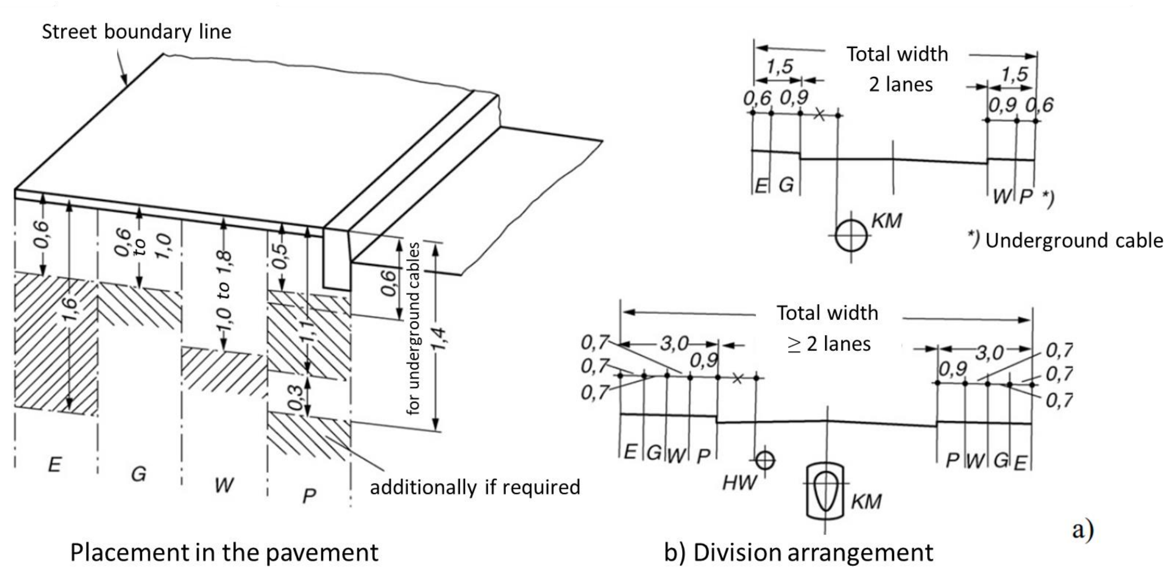


Figure 4. Position of the supply lines in the street cross-section according to German standard DIN 1998 [4].

where: *E* = Electricity; *G* = Gas; *W* = Drinking water; *P* = Mail line; *HW* = Main pipe for drinking water; *KM* = Combined sewer system.

1.2. Road damage due to leaking pipes

Spectacular cases of damage on these higher-level pipelines are a ubiquitous problem and usually cause enormous damage consequences and consequently great media attention and public interest. In the case of major damage, there is a threat of undermining and the associated subsidence of the road surface, in the worst case even leading to sudden subsidence, with fatal accidents (**Figures 5** [5] and **6** [6]).

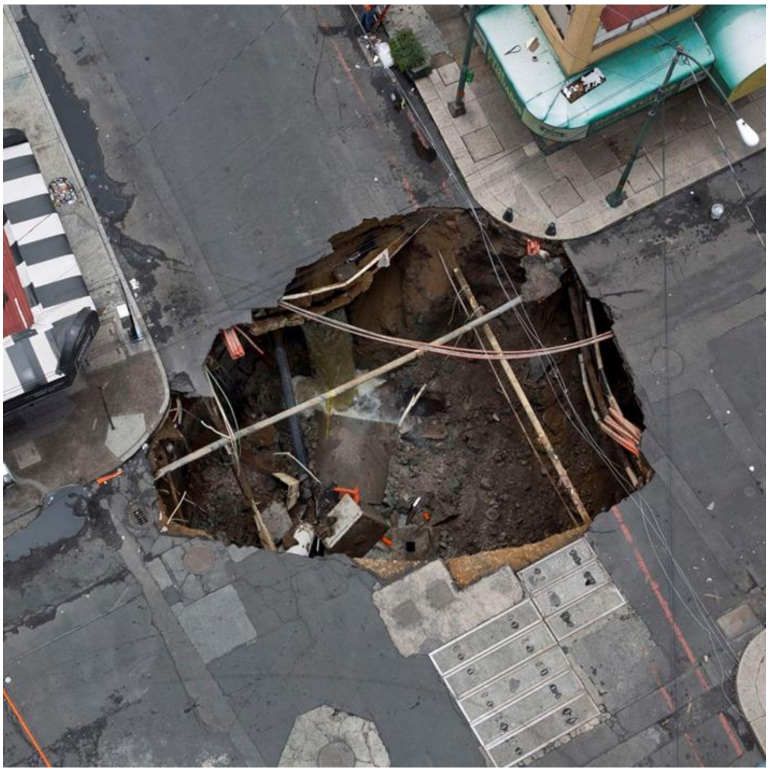


Figure 5. Giant hole in the street [5].

Figure 6. Giant hole in the road [6].

2. Technical basics

2.1. General requirements for pipe materials in pipeline construction

All loads must be able to be absorbed; material strength and wall thickness must be sufficient to:

1) The internal pressure under steady-state and transient conditions
2) The external pressure due to earth loads, traffic loads or groundwater
3) The axial stress due to longitudinal forces (deflection forces at bends, weight of the pipe when not laid horizontally, fluid friction, axial stress during transient processes and temperature changes)
4) Bending moments (settlements in buried pipelines and support forces in exposed pipelines)
5) Withstand the additional stresses during transport and installation of the pipeline.

2.2. Divisions of the pipes based on deformation ratio $\varkappa$

The pipes are divided according to the deformation ratio $\varkappa$ Equation (1) (**Table 1**):

$$\varkappa = \frac{\delta_P}{\delta_S} \tag{1}$$

1) Rigid (rigid) (**Figure 7**)
2) Semi-flexible
3) Flexible (soft to bend) (**Figure 7**)

$\varkappa$: Deformation ratio.

δ_P: Vertical deflection of the pipe.

δ_S: Vertical deformation of the soil to the side of the pipe.

Table 1. Divisions of the pipes based on deformation ratio $\varkappa$ [7].

Deformation ratio $\varkappa$	**Deformation criteria**
$\varkappa \leq 0.05$	Rigid
$0.05 \leq \varkappa \leq 1.0$	Semi-flexible
$\varkappa \geq 1.0$	Flexible

Figure 7 shows bend-resistant and bend-soft pipes.

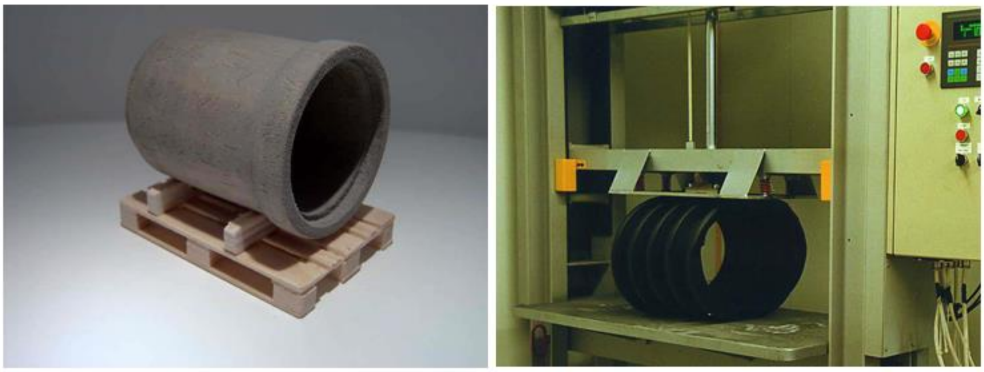


Figure 7. Bend-resistant and bend-soft pipes [8].

Figure 8 shows bend-soft pipes aus GFK (German. “Glasfaserverstärkter Kunstoff”) Glass fibre reinforced plastic, whereby the ring bending elongation at break is 1.6%–2.2% short-term and long-term: 0.5 × short-term value (depending on the pressure rating).

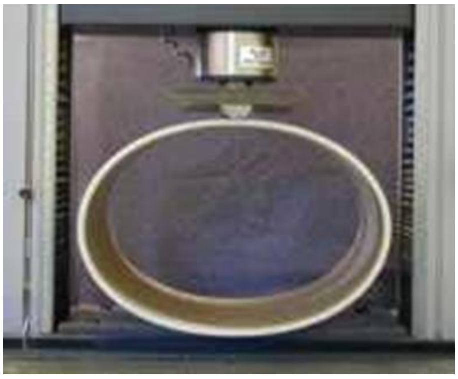


Figure 8. Bend-soft pipe GFK [9].

3. Static calculation of underground pipelines

3.1. Austrian standard OENORM B 5012-structural design of buried water and sewerage pipelines

The deformation of the pipe is mainly caused by subsidence of the soil. Experience shows that the expected settlements and the associated earth movements are completed after about two years. The loads that occur (resulting from surface loads, traffic loads, earth loads, etc.) (**Figure 9**) are not absorbed by the pipe itself in the case of flexible pipes, but are passed on to the surrounding soil. Stresses that occur in flexible pipes are therefore relieved by deformation of the pipe. This restores the equilibrium between the soil and the pipe. The pipe itself then lies in the soil in an almost stress-free state and is thus not exposed to any additional loads. Rigid pipes have to absorb the stresses (**Figure 9**).

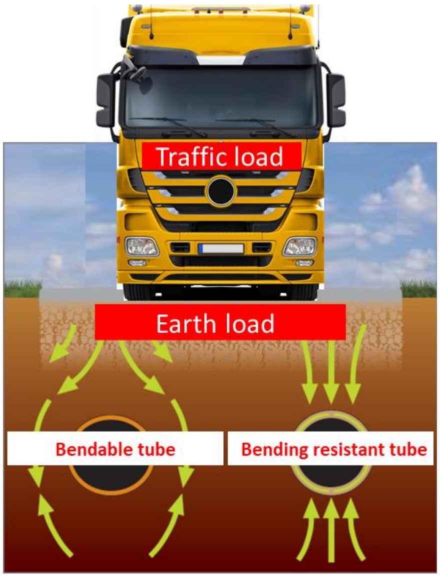


Figure 9. Reduction of stresses in flexible and rigid pipes.

The static calculation of underground pipelines according Austrian Standard OENORM B 5012 [7] and ATV worksheet A 127 [10] is used for load effects such as:

1) Earth pressure,
2) Traffic load,
3) Water pressure from inside and outside, is carried out.

The different pipe materials (pipe stiffness), soil characteristics, installation and bedding conditions are considered (flexural stiff and flexural soft pipes depending on pipe deformation in the soil under load). The static design is carried out on the basis of the following verifications:

1) Structural analysis
2) Deformation check
3) Load capacity verification
4) Stability check.

The purpose of this standard OENORM B 5012 is to provide guidance for the structural analysis of buried pipelines. The calculation is based on generally accepted technical and field-proven principles. This standard contains a calculation method for buried pipelines and determines the stresses of piping systems made of all materials to be used for the transport of water/wastewater in pressure or gravity pipelines. The standard describes the design and structural analysis of buried pipes for all applications in water supply and sanitation on the basis of the calculation of stress, strain and deflection. There are established guidelines for the critical design criteria (stress, deformation and /or deflection calculation). The method is applied for all nominal diameters of pipes. However, for very large diameters the design in the installation of pipes may require the inclusion of other additional parameters, such as the homogeneity of the surrounding soil [7].

3.2. The “Europeanisation” of pipe statics in the field of water management

In 1997, the European standard EN 1295-1: “Structural design of buried pipelines under various conditions of loading-Part 1: General requirements” [11] was adopted. The standard also contains a compilation of nationally introduced calculation methods without a corresponding evaluation. Special features:

1) Static calculation of sewers and pipelines as well as pipelines for water supply. Extension of the scope to pressure pipelines
2) Orientation towards limit states which must not be reached in order not to impair serviceability
3) Consideration of different load cases for pressure pipelines, including the unpressurised state (buckling) and the re-deformation effect as a result of superposition of the external load effects with the internal pressure [12].

This document specifies the requirements for the structural design of water supply pipelines, drains and sewers, and other water industry pipelines, whether operating at atmospheric, greater or lesser pressure. In addition, this document gives guidance on the application of the nationally established methods of design declared by and used in CEN member countries at the time of preparation of this document. This guidance is an important source of design expertise, but it cannot include all possible special cases, in which extensions or restrictions to the basic design methods may apply. Since in practice precise details of types of soil and installation conditions are not always available at the design stage, the choice of design assumptions is left to the judgement of the engineer. In this connection the guide can only provide general indications and advice. This document specifies the requirements for structural design and indicates the references and the basic principles of the nationally established methods of design [11]. The standards control loop is shown in **Figure 10**.

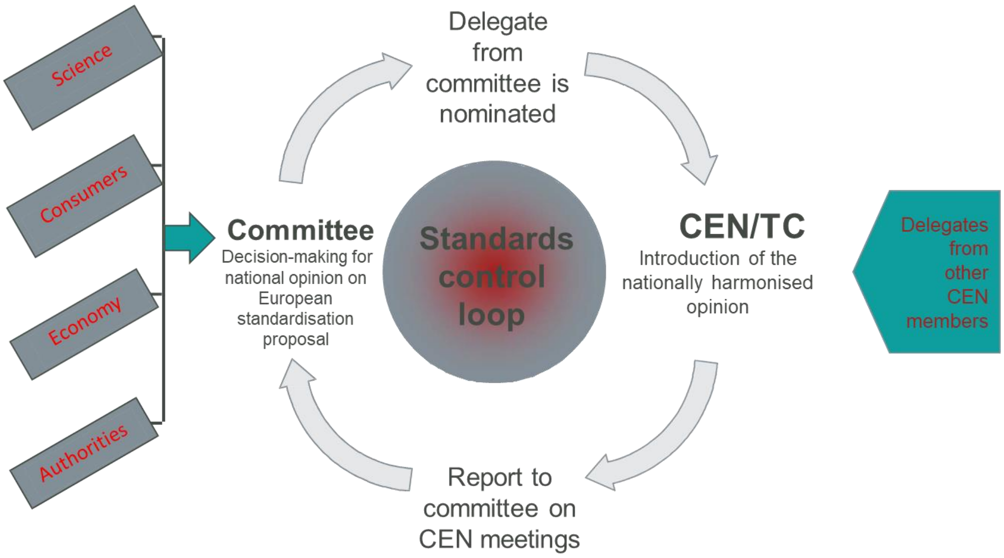


Figure 10. The standards control loop [13] (Edited by author).

3.3. Soil-soil groups including guide values

The soil groups according to the German standard DIN 18196 [14] are divided into the following soil groups:

G1: Non-cohesive soils (GE, GW, GI, SE, SW, SI)

G2: Low cohesion soils (GU, GT, SU, ST)

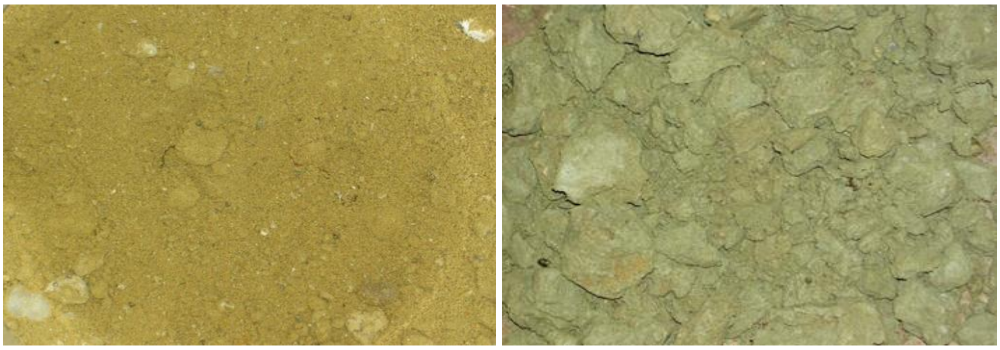
G3: Cohesive mixed soils, silt (e.g., cohesive sand and gravel, cohesive, stony weathered soil, GU, GT, SU, ST, UL, UM)

G4: Cohesive soils (e.g., clay, loam, TL, TM, TA, OU, OT, OH, OK)

The examples of different soil groups are shown in **Figures 11–14**.

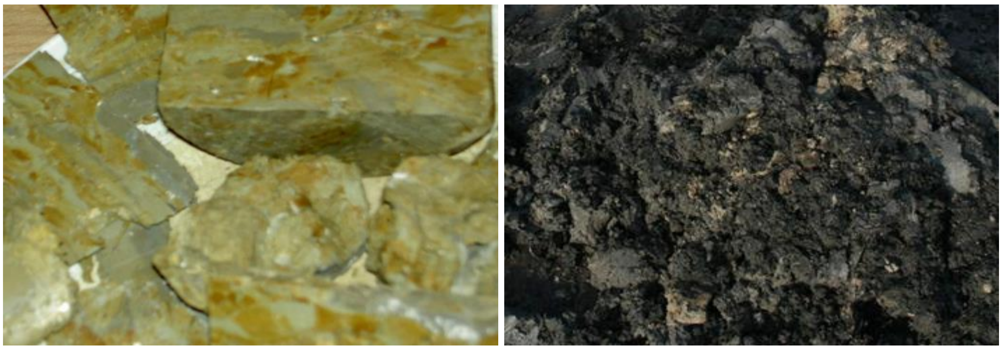
(a) **(b)**

Figure 11. (a) Self-graded gravel (GE); **(b)** coarse-grained, non-cohesive soils (Gravel or sand) (GW, GI, SE, SW, SI) [8].



(a) **(b)**

Figure 12. (a) Mixed-grained, low cohesive soils with a low proportion of fine gravel (gravel or sand with small amounts of silt or clay) (GU, GT, SU, ST); **(b)** Mixed-grained, cohesive soils with a high proportion of fine gravel (gravel or sand with a high proportion of silt or clay) (GU, GT, SU, ST) [8].



(a) **(b)**

Figure 13. (a) Fine-grained, cohesive soils (silt or clay slightly to distinctly plastic) (UL, UM, TL, TA, TM); **(b)** Soils with organic admixtures (OK, OU, OT) [8].

Figure 14. Peat, other highly organic soils (HN, HZ) [8].

The grain size fraction according to the Austrian standard OENORM EN ISO 17892-4 is shown in **Figure 15** [15] and in **Table 2** according to the Austrian standard OENORM EN ISO 14688-1 [16] in two languages, German and English.

Table 2. Grain size fractions according to Austrian standard OENORM EN ISO 14688-1 [16] (Edited by author)

Range	**Naming**	**Abbreviation**		**Grain size**	**Englisch**
		New	**Old**	**mm**	
Very coarse-grained soil	Großer Block	LBo	Y	>630	L. Boulder
	Blöcke	Bo		>200–630	Boulder
	Steine	Co	X	>63–200	Gobbles
Coarse-grained soil	Kies	Gr	G	>2.0–63	Gravel
	Grobkies	CGr	gG	>20–63	Coarse Gravel
	Mittelkies	MGr	mG	>6.3–20	Medium Gravel
	Feinkies	FGr	fG	>2.0–6.3	Fine Gravel
	Sand	Sa	S	>0.063–2.0	Sand
	Grobsand	CSa	gS	>0.63–2.0	Coarse Sand
	Mittelsand	MSa	mS fS	>0.2–0.63	Medium Sand
	Feinsand	FSa		>0.063–0.2	Fine Sand
Fine-grained soil	Schluff	Si		>0.002–0.063	Silt
	Girobschluff	CSi	U	>0.002–0.063	Coarse Silt
	Mittelschluff	MSi	gU	>0.0063–0.02	Medium Silt
	Feinschluff	FSi	mU	>0.002–0.0063	Fine Silt
	Ton	CI	T	<0.002	Clay

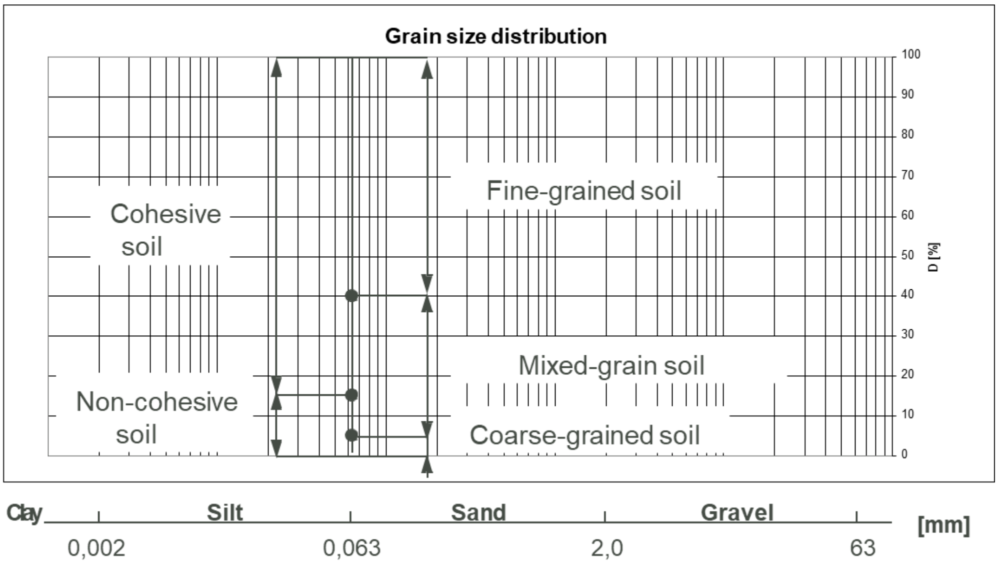


Figure 15. Classification of soils - Determination of particle size according to Austrian standard OENORM EN ISO 17892-4 [15].

The guideline values for the soil groups according to German standard DIN 18196 are shown in **Table 3**.

Table 3. Soil groups-reference values [17].

Soil group	**Weights B**	**Weights under buoyancy B**	**Internal friction angle**	**Deformation modulus E_B in N/mm^2 with degree of compaction D_{Pr} in %**						**Expo-nent z**	**time-dependent behaviour $f1$**
	kN/m^3	kN/m^3		85	90	92	95	97	100	-	-
G1	20	11	35	2	6	9	16	23	40	0. 4	1.0
G2	20	11	30	1.2	3	4	8	11	20	0.5	1.0
G3	20	10	25	0.8	2	3	5	8	13	0.6	0.8
G4	20	10	20	0.6	1.5	2	4	6	10	0.7	0.5

The abbreviations are according to German standard DIN 18196. For soil types that cannot be categorized in **Table 3** (e.g., waste, organic soils, bulk materials), the calculated values must be determined. with G = 1 to 4 for the soil group. The values for $E_B > 2$ N/mm^2 must be rounded to whole numbers. For embankment fill with overburden $h > 5$ m, a load-dependent increase in the deformation modulus is permissible [17]:

$$E_{B,\,\sigma} = E_B \times (p_E/100)^z$$

with p_E in kN/m^2, z and E_B according to **Table 3**.

3.4. Surface load acting on limited areas

In this section, calculation methods for the vertical stresses acting at pipe crown height are very briefly given, whereby the pipe/soil interaction is considered beforehand. The load $p_{A,vl}$ acting on a pipe due to a surface load uniformly distributed over the area A (**Figure 16**) is calculated using the following Equations (2)–(4):

In zone I:

$$pA,vl = \frac{W \times L \times p_{A,GL}}{(W + h) \times (L + h)} \tag{2}$$

In zone II:

$$pA,vl = \frac{W \times L \times p_{A,GL}}{(W + 2 \times h) \times (L + 2 \times h)} \tag{3}$$

In zone III:

$$pA,vl = 0 \tag{4}$$

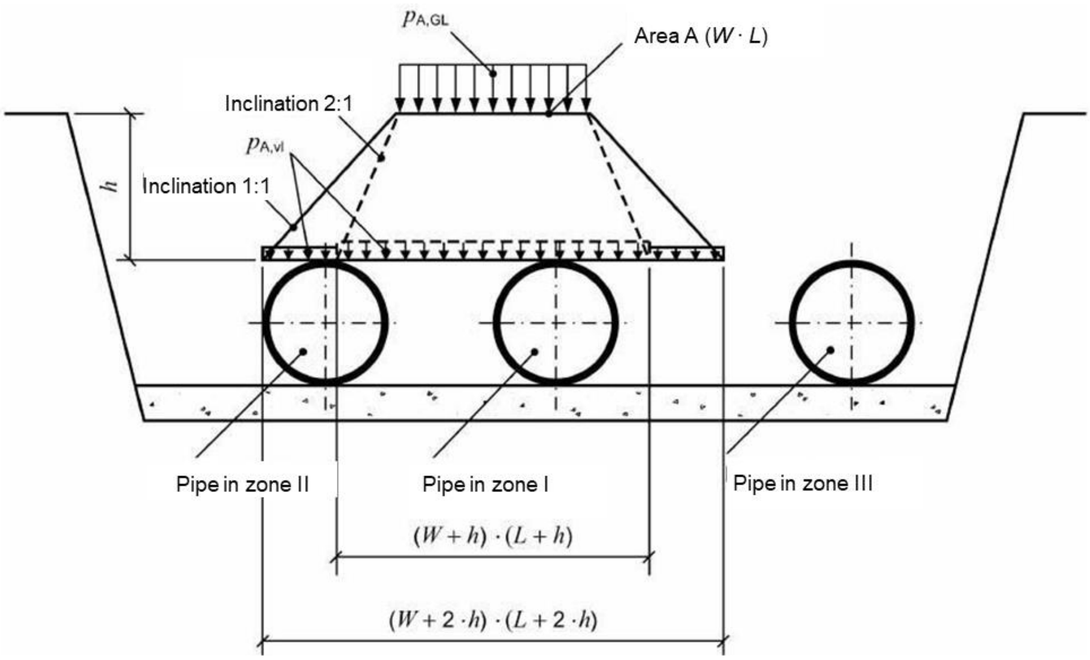


Figure 16. Limited surface load above the pipe [7].

If the surface load $p_{A,GL}$ is a live load, the pipe load $p_{A,vl}$ must be increased by the corresponding dynamic coefficient. If the pipe is located outside the propagation zones, i.e., zone I or zone II, it is not subjected to the surface load.

3.5. Traffic loads according to Eurocode

3.5.1. General

A pipeline can be subject to traffic loads, regardless of whether it is laid underground under a road or in an open field. It is important that the magnitude of the traffic loads and the surface condition (type of superstructure, paved or unpaved) are assessed realistically and specified in the tender. Attention is drawn to the fact that all traffic loads are short-term loads and must be considered as such in the calculation. This means that in the case of long-term calculations, the load caused by traffic loads under short-term conditions must be superimposed on the other (permanent) loads under long-term conditions. This relates both to time-dependent soil properties and pipe properties with regard to deflection, stress and/or deformation as well as to the safety calculation. Tram and railway traffic loads must be assumed in accordance with ÖNORM EN 1991-2 [18].

The loads from motor vehicle and pedestrian traffic on the carriageway and footpaths are to be regarded as variable loads:

Vertical loads: 4 traffic load models (LM 1–4) are provided, whereby the load models LM 1 and LM 2 are always to be used and cover the heaviest traffic on European main lines. Separate load models (choice between 5 models) are provided for the fatigue analyses.

Horizontal loads: Ideal equivalent loads in

a) longitudinal direction (braking or starting) and - only for bridges in curves

b) Transverse direction (centrifugal forces of the vehicles).

Unplanned vehicle impacts are to be regarded as exceptional loads:

1) Impact loads on bridge piers, guide rails and edge strips on the supporting structure
2) Vehicles veering off the carriageway
3) Railing loads
4) Vehicle loads on abutment hearth walls

3.5.2. Load models

Table 4 provides an overview of the load models to be considered [19].

Table 4. Overview of the load models to be considered [19]. (Edited by author).

Load model	Application	Purpose	Stress		Traffic lane	Charakter
			global[a]	local[b]		
LM 1	Always	General traffic	Yes	Yes	Yes	Equal load & double axis sec (Abbreviation: UDL & TS)[d]
LM 2	Always	Maximum axle load	-	Yes	-	Single axis
LM 3	According to requirements[e]	Special vehicles	Yes	Yes	Yes	Special vehicle & LM 1
LM 4		Crowds of people	Yes	-	-	Equal load

a. Main load-bearing effect (main girder).
b. Road load.
c. Arrangement in every single lane (double axle only on number 1–3).
d. UDL…uniformly distributed load, TS… Tandem system.
e. specified in the National Application Document (NAD) or prescribed by the authority.

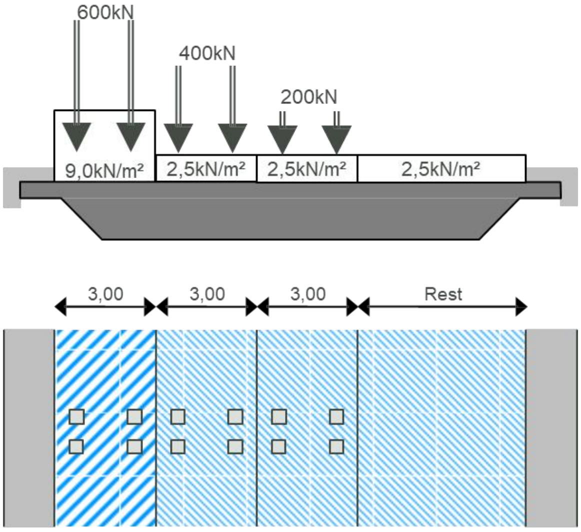


Figure 17. Load model 1 (LM 1) for road traffic [19].

An example of the load configuration (LM 1) in the transverse direction of the bridge for a structure with two carriageways of 7.0 m each or 2 lanes of 3.0 m each is shown in **Figures 17** and **18**.

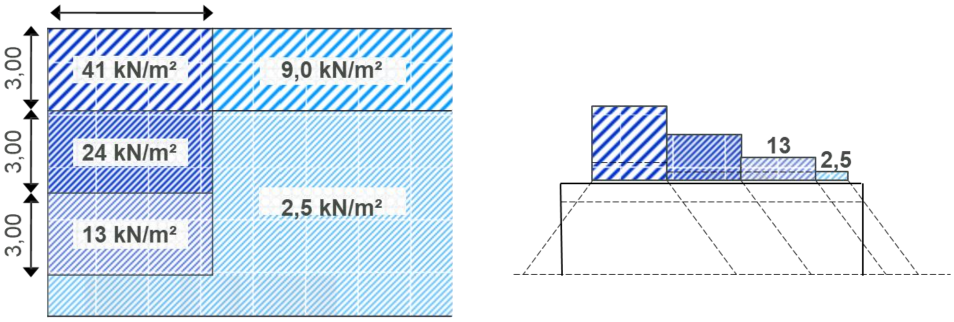


Figure 18. Road traffic-load model 1: a) ground plan; b) cross-section [19].

3.6. Load distribution according to Austrian standard OENORM B 5012

Like the load, the load distribution also has a major influence on the static behaviour of the pipe. The load distribution depends on the behaviour of the pipe and the surrounding soil. This interaction is influenced by the compaction above and next to the pipe and the design of the pipe support. If the deformability of the pipe and the soil in the zone of influence is unequal, the vertical stresses calculated in accordance with Section 6 [7] are redistributed at the level of the pipe crown. The concentration factors λ according to 8.3 [7] are used as a measure for this stress redistribution (stress increase over rigid and semi-flexible pipes, stress reduction for flexible pipes). The idealised form of the redistributed stresses is shown in **Figures 19** (for rigid and semi-flexible pipes) and **20** (for flexible pipes).

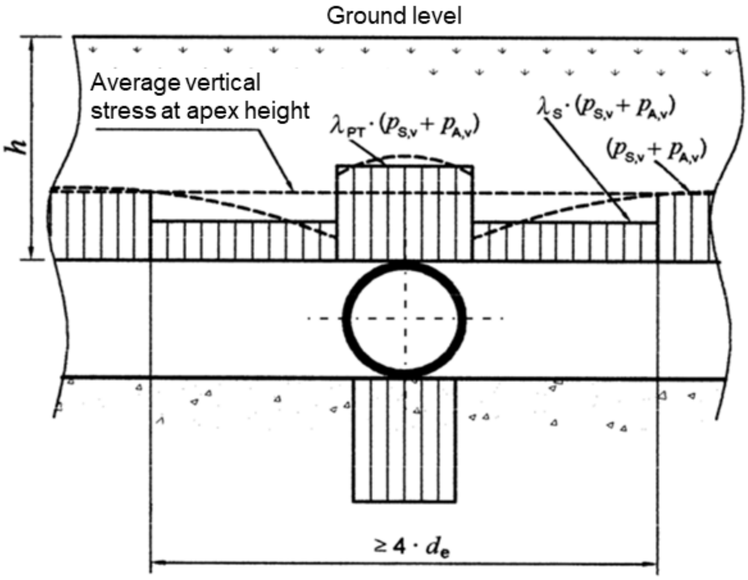


Figure 19. Distribution of vertical floor stresses for rigid and semi-flexible pipes [7].

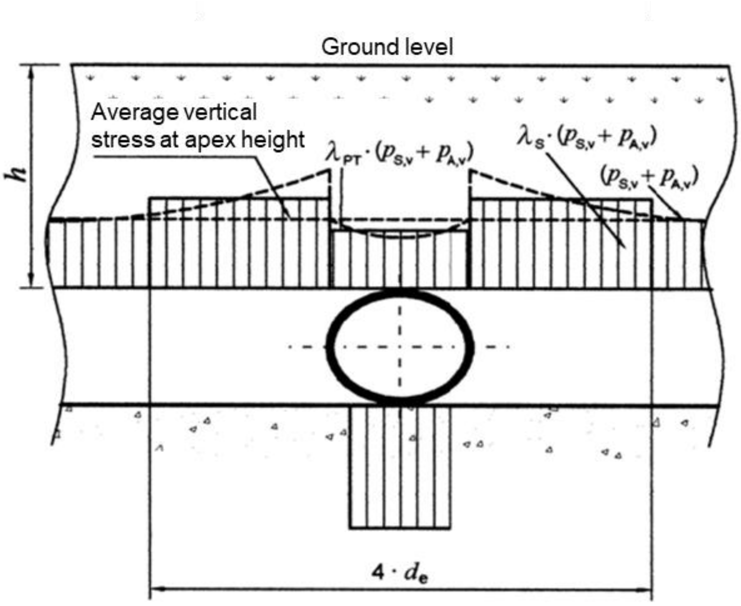


Figure 20. Distribution of vertical floor stresses in flexible pipes [7].

3.7. Embedding types according to Austrian standard OENORM B 5012

The embedding type has a significant influence on the distribution of the load around the circumference of the pipe [20].

3.7.1. ET1 (embedding type 1)

The pipe is laid directly on either the specially pre-treated or non-pre-treated channel base (**Figure 21**).

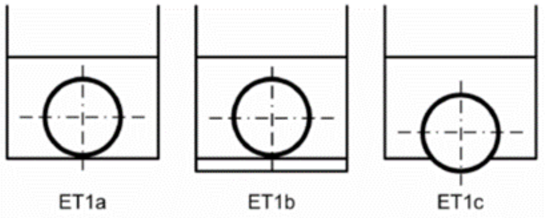


Figure 21. Embedding type with pre-treated or without pre-treated support on grown soil [7].

3.7.2. ET2 (embedding type 2)

The lower support zone consists of the same material as the upper support zone and the side backfill. The same soil properties in terms of soil group and compaction can be assumed for these (**Figure 22**).

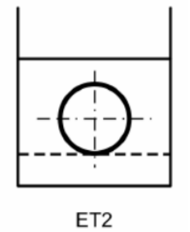


Figure 22. Embedding type with prepared sole zone [7].

3.7.3. ET3 (embedding type 3)

The soil properties in terms of soil group and compaction are different in the support zone (including spandrel) and the side fill (**Figure 23**).

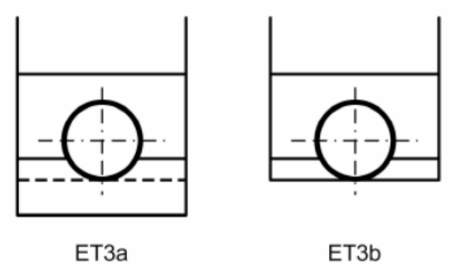


Figure 23. Embedding type with support on sand-gravel bed [7].

3.7.4. ET4 (embedding type 4)

The pipe is embedded on a concrete support. This type of embedding is not permitted for flexible pipes (**Figure 24**).

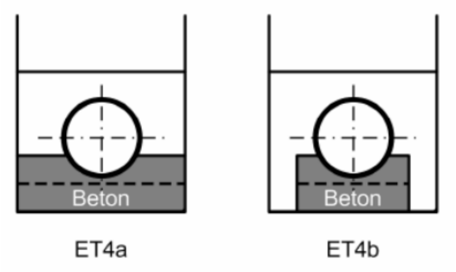


Figure 24. Embedding type with support on concrete (Germ. “Beton”) [7].

3.8. Pressure distribution around the circumference of the pipe

The pressure distribution around the circumference of the pipe depends on the design of the support, the backfill in the pipe zone and the deformation behaviour of the pipeline. The surcharge load is assumed to be rectangular distributed and vertically directed for all pipe types, regardless of the type of installation. The lateral pressure acting on a pipeline is composed of q_h due to vertical earth load and the bedding reaction pressure q_{h*} due to pipe deformation. The lateral pressure q_h depends on the vertical pressure in the soil next to the pipeline. The bedding reaction pressure q_{h*} is parabolic and has an opening angle of 120° [21]. (**Figures 25** and **26**).

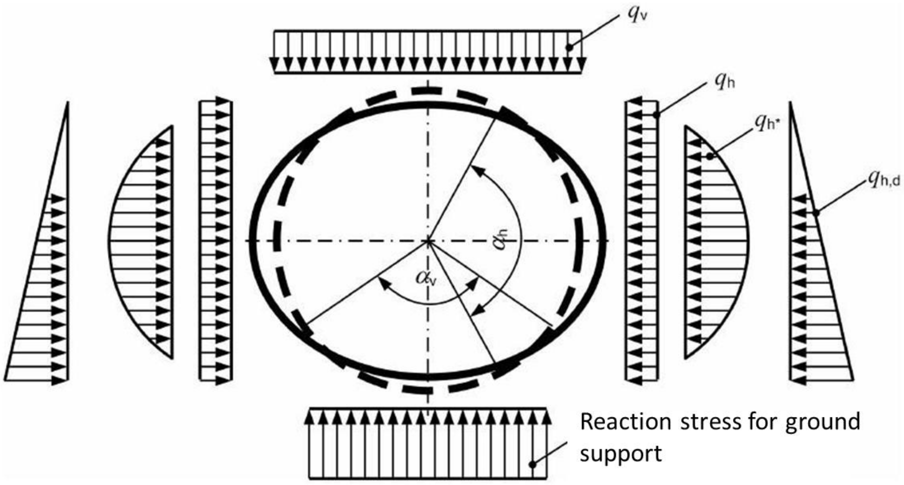


Figure 25. Earth pressure distribution at the pipe circumference for ground supports (see ET1, ET2 or ET3) [7].

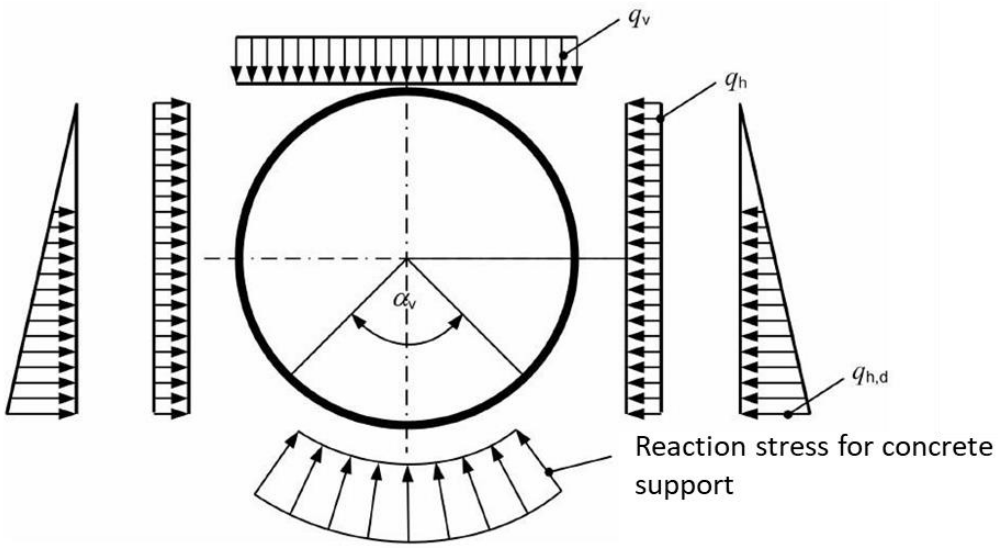


Figure 26. Earth pressure distribution at the pipe circumference for concrete supports (see ET4) [7].

3.9. No concrete embedding for the flexible pipes

The static calculation is often carried out by the pipe manufacturers. Simplified calculation is summarised briefly like this: For bending-resistant pipes with a defined minimum crushing force FN (also referred to as FN_{min} in kN/m), the required installation condition ("installation figure EZ")-pipe bedding, pipe encasing with concrete—is calculated as a function of the total vertical load *FG* acting on the pipe and a safety factor ≥ 1.5 (load-bearing capacity verification) (Equation (5)):

$$\text{FN} \times \text{EZ}/\text{FG} \geq 1.5 \qquad (5)$$

The bending-resistant pipes are divided into different load-bearing capacity classes (pipe classes with class number, e.g., 95, 120, 160...). The minimum crushing force FN is calculated for pipes ≥ DN 200 with FN = class number-DN/1000 (e.g., pipe class 120, DN 300 ... FN = 120 − 300/1000 = 36 kN/m).

With regard to the widespread assumption that concrete work in the area of plastic pipelines has positive effects in terms of stability, it must be noted that the opposite is often the case-concrete encasement (or bedding on/in concrete) has a detrimental effect on pipe statics (**Figure 27**). This can be explained by the fact that pipes made of thermoplastics (PE, PP and PVC) are flexible pipes that yield to a certain extent under the effect of load (traffic load, but also unavoidable settlements of the soil) and thus the load is transferred via the gravel or chippings bedding ("interlocking" of the edge grain). If there is now a concrete bedding or even encasement, the positive property of flexibility is erased and the pipe functions to put it exaggeratedly—as a lost formwork. If the concrete is then damaged as a result of loads, it cannot be ruled out that the pipe will also be damaged, which can result in clearly visible damage at the top edge of the terrain.

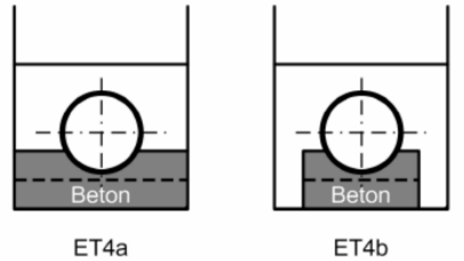


Figure 27. ET4 (embedding type 4, including subtypes a) and b): The pipe is embedded on a concrete bedding. This embedding case is not permissible for flexible pipes [7]!

The flexibility of a PE (polyethylene) pipe can be seen very impressively in **Figure 28**. The welded PE pipes even stop a road slide and did not break in the process.

Figure 28. The welded PE pipes stop a road slide [22].

In accordance with the harmonised European standard OENORM EN 1610 [23], construction materials for the pipe zone must comply with the respective subsections of 5.3 in order to ensure permanent stability and load-bearing capacity of the pipeline in the ground. These construction materials must not impair the pipe, the pipe material or the groundwater. Frozen material must not be used. Construction materials for the pipe zone must comply with the planning requirements. These materials may either be in-situ soil that has been tested for suitability or supplied building materials.

Construction materials for the bedding should not contain any components that are larger than:

1) 22 mm with DN ≤ 200,
2) 40 mm with DN > 200 until DN ≤ 600.

The building materials listed below are suitable for the pipe zone. These can also be recycled building materials [23]:

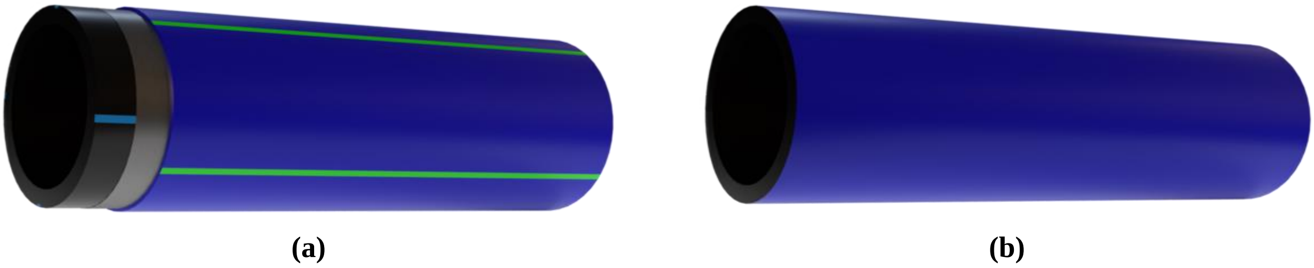
1) Granular, unbound building materials
2) Granular, unbound building materials are:
3) Single-grain gravel;
4) Material with graded grain size;
5) Sand;
6) Grain mixtures (all-in);
7) Crushed building materials.

Although the OENORM EN 1610 standard [23] also recommends ‘sand’ as a construction material for the performance zone, the author would advise against it based on his 17 years of experience as a civil engineering construction manager in one of the largest construction companies in Europe. According to **Figure 15** Classification of soils-Determination of particle size according to Austrian standard OENORM EN ISO 17892-4 [15], the range of sand particle size is from 0.063 mm to 2.0 mm. Any construction material that contains fines (0.063 mm) must be compacted accordingly when installed as a construction material in trench construction, which unfortunately very often does not happen in the ‘heat of labour’ and the settling on the surface is the result. Likewise, the fine fraction (0.063 mm) in the bedding material absorbs the water penetrating into the trench and if the water drains into the surrounding, grown soil over time, this in turn can cause subsidence on the surface. The best bedding material in the author’s 17 years of experience is 4/8 mm chippings (see **Figures 29** and **30**) or 8/16 mm chippings (depending on the diameter of the pipe) because the material is, firstly, WATER PERMEABLE and, secondly, sharp-edged, so that the broken grains, when installed correctly, literally wedge into each other, which significantly increases its stability and resistance to subsidence.

Figure 29. Chippings 4/8 mm (Germ. “Splitt”) as bedding material [24].

Figure 30. Dolomit Chippings 4/8 mm LSK as bedding material [25].

As far as the bedding material is concerned, there are also exceptions for very special pipes. Solid-wall pressure pipes made of PE100-RC with coloured stripes (PAS 1075 Type 1) or co-extruded solid-wall pressure pipes with a dimensionally integrated, coloured outer layer (PAS 1075 Type 2) to identify the medium. RCprotect® is particularly resistant to the consequences of scratches caused by the absence of sand bedding and the point loads that occur over a longer period of time. GEROfit® R drinking water pressure pipe type 3 to PAS 1075 Drinking water pressure pipe to DIN EN 12,201 made of PE100-RC, type 3 to PAS 1075 with maximum resistance to slow crack growth and additive protective jacket made of modified polyolefin compound; suitable for laying in trenches with and without a sand bed as well as for laying with or without a trench. These special pipes can be seen in **Figure 31** [26].



(a) **(b)**

Figure 31. (a) GEROfit® R pressure pipe with protective jacket for trenchless installation methods, additional protective functions such as notch/scratch and crack resistance; **(b)** RCprotect® pressure pipe made of PE100 RC for more efficiency, safety and particularly high crack resistance for alternative pipe laying [26].

3.10. Characteristic values of the pipe materials

The following tables show the characteristic values of the pipe materials that are necessary for the calculations (especially static calculations).

3.10.1. Stoneware pipes (Stz) (Germ. "Steinzeug")

In accordance with DIN EN 295 [27] and works standard WN 295, N = normal load pipe, H = high load pipe. See **Table 5**.

Table 5. Characteristics of stoneware pipes [17].

DN		**100**	**125**	**150**	**200**	**250**	**300**	**350**	**400**	**450**	**500**	**600**	**700**	**800**	**900**	**1000**	**1200**	**1400**
F_N in kN/m	N	34	34	34	32	40	48	56	64	-	60	57	60	60	60	60	60	60
	H	-	-	-	48	60	72	70	80	72	80	96	84	96	-	-	-	-
d_i in mm	N	100	126	151	200	250	300	348	404	-	496	597	697	797	897	998	1198	1396
	H	-	-	-	200	250	300	348	398	447	496	597	697	797	-	-	-	-
d_a in mm	N	131	159	186	242	299	355	417	486	-	581	687	795	895	1008	1119	1320	1550
	H	-	-	-	254	318	376	430	492	548	609	721	831	941	-	-	-	-

3.10.2. Concrete pipes with circular cross-section (Bet) (Germ. “Beton”)

According to German standard DIN 4032 [28], K = concrete pipe with circular cross-section without base, KF = circular cross-section with base; KW = circular cross-section without base, wall-reinforced, KFW = circular cross-section with base, wall-reinforced; wall thicknesses s1 (transom), s2 (crown), s3 (base). See **Table 6**.

Table 6. Characteristic values of concrete pipes with circular cross-section [17].

DN = d_i in mm		**100**	**150**	**200**	**250**	**300**	**400**	**500**	**600**	**700**	**800**	**900**	**1000**	**1200**	**1400**
F_N in kN/m	K, KF	24	26	27	28	30	32	35	38	41	43	-	-	-	-
	KW, KFW	-	-	-	-	50	63	80	98	111	125	138	152	181	207
d_a in mm	K, KF	144	198	252	310	380	490	600	720	840	950	-	-	-	-
	KW	-	-	-	-	400	530	670	800	930	1060	1190	1320	1580	1840
	KFW	-	-	-	-	400	500	640	770	900	1030	1160	1290	1540	1840
s_1	KF	22	24	26	30	40	45	50	60	70	75	-	-	-	-
s_2, s_3		22	24	26	30	40	45	60	70	80	90	-	-	-	-
s_1	KFW	-	-	-	-	50	50	70	85	100	115	130	145	170	200
s_2		-	-	-	-	50	65	85	100	115	130	145	160	190	220
s_3		-	-	-	-	65	90	110	130	150	170	195	215	260	300
σ_R in N/mm^2	K, KF	6.1	7.7	8.7	8.4	6.2	6.8	7.4	6.7	6.2	6.4	-	-	-	-
	KW	-	-	-	-	6.9	6.8	6.4	6.8	6.7	6.8	6.7	6.8	6.8	6.8
	KFW	-	-	-	-	6.9	11.0	9.1	9.1	8.7	8.4	8.2	8.1	8.4	8.1

3.10.3. Concrete pipes with egg-shaped section (Bet)

In accordance with German standard DIN 4032 [28], EF = concrete pipe with egg-shaped section with base, wall thicknesses s1 (transom), s2 (crown), s3 (base). See **Table 7**.

Table 7. Characteristic values of concrete pipes with egg-shaped cross-section [17].

d_i × h_i in mm		**500 × 750**	**600 × 900**	**700 × 1050**	**800 × 1200**	**900 × 1350**	**1000 × 1500**	**1200 × 1800**
F_N in kN/m	EF	61	69	75	77	80	83	86
d_a × h_a in mm		628 × 918	748 × 1096	868 × 1270	988 × 1444	1104 × 1618	1220 × 1792	1444 × 2120
s_1 in mm		64	74	84	94	102	110	122
s_2, s_3 in mm		84	98	110	122	134	146	160
σ_R in N/mm^2		9.5	9.6	9.4	8.8	8.7	8.6	8.6

3.10.4. Ductile cast iron pipes (GGG) (germ. "Globularer Grauguss")

According to German standard DIN EN 598 [29], increased wall thicknesses according to DIN EN 545 [30]; s_{ZM} cement mortar lining (when determining the pipe stiffness, s may be increased by $s_{ZM}/6$), S minimum ring stiffness (determined with d_m). See **Table 8**.

Table 8. Characteristic values of ductile cast iron pipes [17].

DN	**100**	**125**	**150**	**200**	**250**	**300**	**350**	**400**	**500**	**600**
d_a in mm	118	144	170	222	274	326	378	429	532	635
s in mm	5	5	5	5	5.3	5.6	6	6.3	7	8.8
s_{ZM} in mm	3.5	3.5	3.5	3.5	3.5	3.5	5	5	5	5
S in kN/m^2	250	130	80	60	54	47	36	30	22	18
DN	700	800	900	1000	1200	1400	1600	1800	2000	
d_a in mm	738	842	945	1048	1255	1462	1668	1875	2082	
s in mm	9.6	10.4	11.2	12	15.3	17.1	18.9	20.7	22.5	
s_{ZM} in mm	6	6	6	6	7,5	9	9	9	9	
S in kN/m^2	24	20	18	16	20	18	17	16	16	

3.10.5. Solid wall pipes made of polyvinyl chloride (PVC-U) (U = unplasticized)

According to German standard DIN EN 1401-1 (DIN 2023) (fittings: DIN V 19 534), nominal ring stiffness SN in kN/m^2 (determined with d_m). See **Table 9**.

Table 9. Characteristic values of solid wall pipes made of polyvinyl chloride [17].

DN/OD = d_a in mm		**110**	**125**	**160**	**200**	**250**	**315**	**400**	**500**	**630**	**800**	**1000**
min s in mm	SN 4	3.2	3.2	4.0	4.9	6.2	7.7	9.8	12.3	15.4	19.6	24.5
	SN 8	3.2	3.7	4.7	5.9	7.3	9.2	11.7	14.6	18.4	-	-

3.10.6. Solid-wall pipes made of high-density polyethylene (PE-HD) (HD = high density)

According to German standard DIN 19,537 [31] and DIN 8074 [32], nominal ring stiffness SN in kN/m^2 (determined with d_m). See **Table 10**.

Table 10. Characteristic values of solid-wall pipes made of high-density polyethylene [17].

DN		**100**	**100**	**125**	**125**	**150**	**150**	**200**	**200**	**250**	**250**
d_a in mm		110	125	125	140	160	180	200	225	250	280
s in mm	Series 2 (SN 1)	3.5	-	3.9	4.4	5.0	-	6.2	7.0	7.8	8.7
	Series 3 (SN 2)	4.3	-	4.9	5.4	6.2	-	-	8,7	-	10.8
	Series 4 (SN 8)	-	7.1	-	8.0	-	10.2	-	12,8	-	15.9
DN		300	300	400	500	600	700	800	900	1000	1200
d_a in mm		315	355	450	560	630	710	800	900	1000	1200
s in mm	Series 2 (SN 1)	9.8	-	14.0	17.4	19.6	22.1	24.9	28.0	31.1	37.3
	Series 3 (SN 2)	-	13.7	17.4	21.6	24.3	27.4	30.8	34.7	38.5	46.2
	Series 4 (SN 8)	-	20.1	25.5	31.7	35.7	40.2	45.3	-	-	-

3.10.7. Profiled pipes SN 8 made of polypropylene (PP)-ULTRA RIB 2

According to plastic pipe manual and company specifications, nominal ring stiffness SN in kN/m^2 (determined with d_m). The cross-sectional values required for the static calculation are specified, see ATV-A 127 [10], Section 9.6. ZS-Distance of the centre of gravity of the pipe wall, measured from the inside. See **Table 11**.

Table 11. Characteristic values of profiled SN 8 polypropylene pipes [17].

DN	**150**	**200**	**250**	**300**	**400**	**500**
d_i in mm	148.6	1964	245.3	293.1	394.8	491.5
d_a in mm	170	225	280	335	450	560
A in mm^2/mm	3.93	5.42	6.91	8.56	9.07	12.12
I in mm^4/mm	24.16	56.76	110.90	191.04	459.55	894.76
W_i in mm^3/mm	8.44	15.85	25.55	37.45	59.22	93.10
W_a in mm^3/mm	3.63	6.74	11.48	16.75	29.19	47.36
z_s in mm	2.86	3.58	4.34	5.10	7.76	9.61

3.10.8. Pipes made from glass fibre reinforced plastic (UP-GF), centrifugally cast

In accordance with German standard DIN 16869-1 [33] and German standard DIN 19565 [34], nominal ring stiffness SN determined with dm; GRP pipes, wound in accordance with German standard DIN 16868 [35] see plastic pipe manual. See **Table 12**.

Table 12. Characteristic values of glass fibre reinforced plastic pipes [17].

Diameter series 2, DN		**200**	**250**	**300**	**350**	**400**	**500**				
d_a in mm		220.8	272.6	324.5	376.1	427.1	530.2				
s in mm	SN 5000 in N/m^2 = SN 5 in kN/m^2	4.9	5.7	6.6	7.5	8.3	10.0				
	SN 10,000 in N/m^2 = SN 10 in kN/m^2	5.8	6.9	8.0	9.1	10.2	12.3				
Diameter series 1, DN		600	700	800	900	1000	1200	1400	1600	1800	2000
d_a in mm		616.4	718.8	820.4	924.1	1026.1	1229	1439	1638	1842	2047
s in mm	SN 5000 in N/m^2	11.5	13.2	14.9	16.6	18.3	21.7	25.5	28.5	31.9	35.3
	SN 10,000 in N/m^2	14.1	16.3	18.4	20.6	22.8	27.0	31.5	35.7	40.0	44.2

The characteristic values of the various pipe materials are shown in **Table 13**.

BSt 500 P.

Long-term value for two years (creep factor: S_{0K}/S_{0L}).

For pressure pipes, the equivalent stress σV applies for the internal pressure load case; for plastic pipes, it is determined from the creep internal pressure test [13.66].

This results in the calculated value of the edge expansion $\varepsilon_R = \pm\ 4.28/d_m$ ($\Delta d_{\text{Break}}/d_m$).

Table 13. Characteristics of the various pipe materials [17].

Pipe material	Weights γ_R	Calculated value of the modulus of elasticity E_R		Calculated value of the bending tensile strength σ_R		Vibration amplitude $2\sigma_A$
	kN/m³	N/mm²		N/mm²		N/mm²
Stoneware	22	50,000		from F_N		EN 295-1 0,4 $ß_{RBZ}$
Concrete	24	30,000		6.0 or from F_N		80
Reinforced concrete	25	30,000		DIN 4035		DIN 4227
Prestressed concrete	25	39,000		DIN 4227		
Ductile cast iron (ZM)	70.5	170,000		550		135
Cast iron lamellar graphite	71.5	100,000		350, with DN ≥ 250: 332		70
Steel (ZM)	77	210,000		336		ATV-A 161
		Short-term E_{RK}	Long-term E_{RL} 2)	Short-term σ_R	Long-term σ_{RL} 3)	
PVC-U	14	3000	1500	90	50	
PP-B and PP-H PP-R	9	1250	312	39	17	see A 127, Tab. 3
	9	800	200	27	14	Footnote 18
PE-HD	9.4	800	160	21	14	
UP-GF	17.5	Calculated values in N/m²		Calculated values from $\Delta d_{Break}/d_m$ in % 4)		
		S_{0K}	S_{0L}			
Nominal ring stiffness SN 1250		1250	625	30	18	
SN 2500		2500	1250	25	15	see A 127, Tab. 3
SN 5000		5000	2500	20	12	Fottnote 18
SN 10,000		10,000	5000	15	9	

4. Analysis of a damage case as an example of the interaction between channel and pavement

4.1. General

The consequences of leaking house connections must be considered in the context of the general functions of pipes and considered accordingly. In accordance with the research assignment, however, only underground pipes are considered below, and here mainly the pipes for underground property drainage, i.e., wastewater and rainwater pipes [36].

4.2. Damage site in fleigestrasse, in front of house no. 11

In Fleigestrasse, in front of house no. 11, a leak was detected in the sewer in the area of a house connection socket. On the surface of the asphalt pavement of the roadway above, there was a trough-like deformation, an outbreak and cracking at the same location (**Figure 32**). The damage site is located in the network node section 5407 between the junction of Fleigestrasse with Schuerckmannstrasse (NK 6041 050) and the junction of a footpath and cycle path with Fleigestrasse (NK 6041 049) (**Figure 33**) [36].

Figure 32. Road damage: Trough-like deformation, breakout, patching [36].

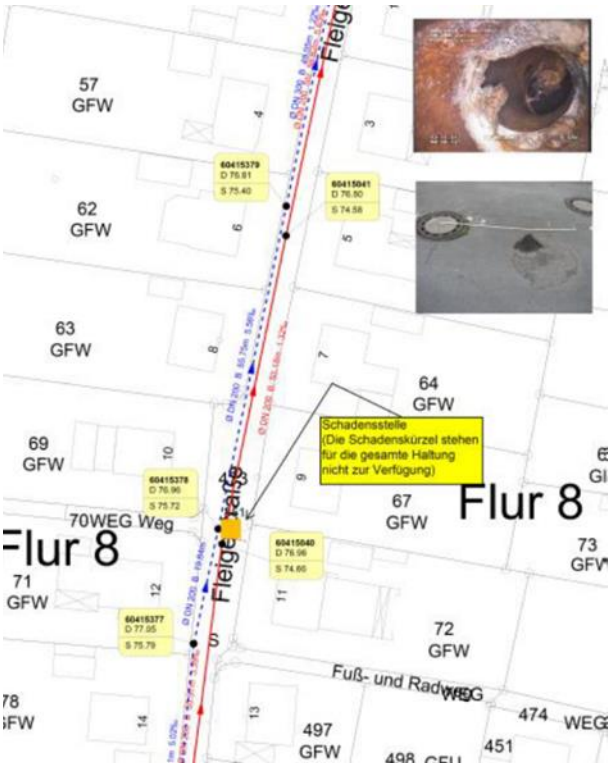


Figure 33. Location plan of the damage site [36].

In the area of the damage site, the rainwater and wastewater sewers are laid under the roadway; both have a manhole adjacent to each other. Approximately 1.17 m away from the manhole 6041 5040 of the 6041 5040 → 6041 5041 connection, a house connection pipe opens into the foul water sewer. In the area of this house connection pipe, the penetration of groundwater was detected during the inspection of the sewer network (**Figure 34**) [36].

The results of the georadar measurements reveal structural disturbances in the superstructure and in the pipe trench backfill that extend below the surface of the asphalt pavement (**Figure 35**). In the vertical section of the measurement results of the 400 MHz sensor, a slump funnel can be seen above the leaking socket. The horizontal sections of the 900 MHz sensor results show structural disturbances at a depth of 1.20 m and 1.60 m below the pavement surface (**Figure 36**). Due to the depth of the sewer pipe (approx. 2.10 m), it is not possible to explore the area directly at the sewer pipe with the method, as sufficient resolution can no longer be achieved with the available antennas at these depths (**Figure 37**) [36].

Figure 34. Damage situation in the main sewer (left) and in the area of the house connection spigot with view into the connection sewer (right) [36].

Figure 35. Georadar measurement: measurement grid of the measurement lines [36].

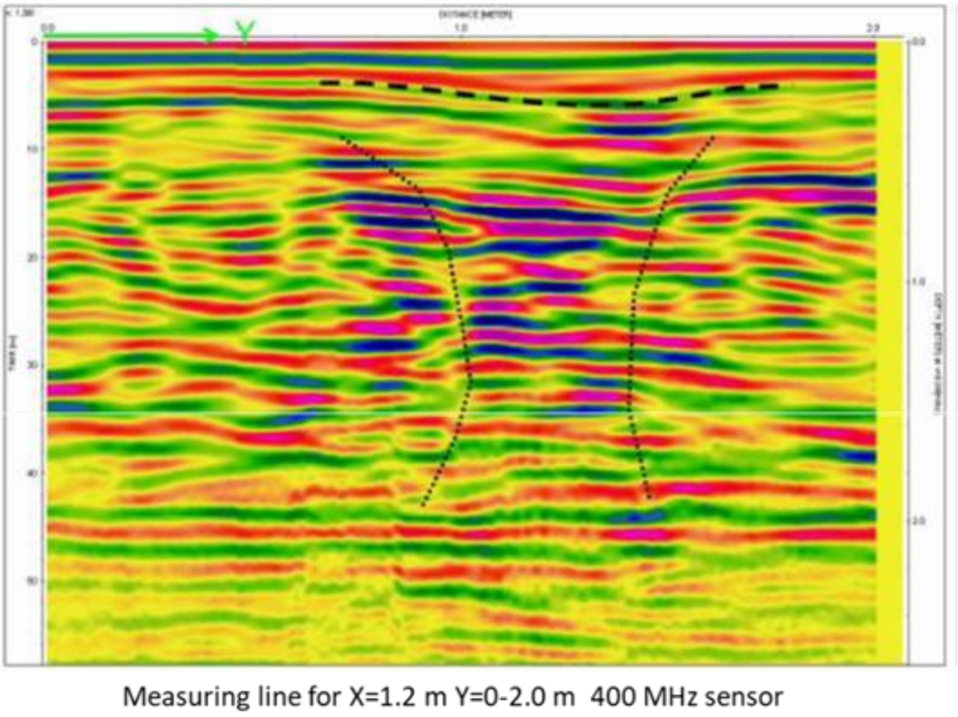
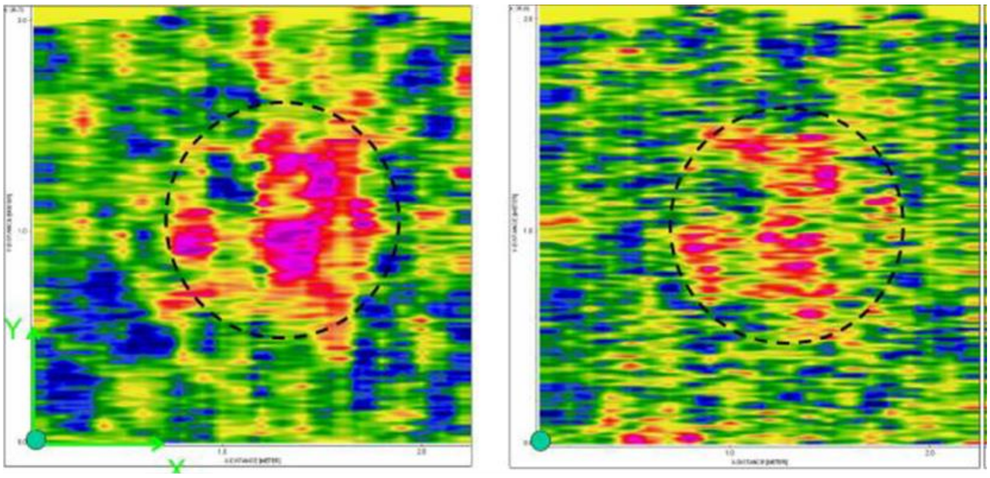


Figure 36. Measurement results 400 MHz sensor: vertical section approximately in the middle of the measurement grid [36].



Depth section (top view) at a depth of approx. 1.2 m 900 MHz sensor
(a)

Depth section (top view) at a depth of approx. 1.6 m 900 MHz sensor
(b)

Figure 37. Measurement results 900 MHz sensor: **(a)** Horizontal sections at a depth of 1.20 m; and **(b)** 1.60 m [36].

5. Conclusion

The generally applicable rules for sewers and other pipes in public areas were first published in Germany in 1931 with the then German standard DIN 1998-Guidelines for the classification and treatment of gas, water, cable and other pipes and fittings in the planning of public roads (2nd edition 1940, 3rd edition 1941, latest edition 2018 [4]). The type, number and distribution of pipes located in a street cross-section are primarily dependent on site-specific conditions, such as road width, drainage procedures, abutters and building development. Public traffic areas serve both as traffic routes and as essential infrastructure routes for accommodating supply and disposal lines. The German standard DIN 1998 defines the requirements for the installation of supply and disposal lines in new public traffic areas and specifies how line zones should be determined. Existing lines continue to be protected. It is recommended that this standard is also considered when reorganising existing lines and when laying them outside public traffic areas. However, the provisions of the DIN 1998 standard do not release you from the obligation to obtain information on cables. The road construction authority is responsible for keeping a list of the lines in its area of responsibility. This standard does not cover: a) the construction and dismantling of pipelines; b) above-ground pipelines; c) pipelines on bridges; d) pipelines on federal motorways; e) service lines [37].

Sewers and water pipes must be stable, functional and leak-proof, and these, together with the other pipes laid in the road body, constitute an overall system. The investigation of this overall system, especially of the sewer and the subsoil, is of great importance when the beach safety of the road is already in doubt due to pipe damage, subsidence or soil collapse at the surface. If this is not taken seriously and the necessary measures are not taken immediately, the consequences can be catastrophic.

Conflict of interest: The author declares no conflict of interest.

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