Structural analysis

Project: TM 4-2019

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Calculation no.: WID18580/19161

Date: 11/02/2020

Description: Ermüdungsnachweis bei Stahlrohren - Nachweisformate im Vergleich
Unterschiede in der Eingabe siehe Register 'Metall'

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1 Jacking pipe according to DWA-A 161, 2nd edition: hü = 2 m Regelwerk

Correction sheet dated May 2017 is considered.

Caption of this part of the calculation:	hü = 2 m Regelwerk
Assumptions:	Überdeckungshöhe > 1,5 m 5x10^6 anwendbar "Regelwerk" entspricht dem aktuellen Stand der Technik, so wie ihn IngSoft derzeit interpretiert - und der sich in der Zukunft ändern kann

Kind of calculation:	Solid wall
States to be calculated:	Only operational state
Add sketch to print:	Yes
Print minimum sectional forces in operational state:	Yes

1.1 Input

1.1.1 Jacking method

Dynamic jacking pipe:	No
Method:	Manual input
Kind of soil dislocation:	None
Complete and permanent grouting of the annular gap:	No
Using of proppant or lubricant:	No
Annular gap:	Other jacking techniques, continous support of annular gap with documentation

1.1.2 Routing and jacking force

Jacking route:	Straight line		
Calculation of the unplanned deviations from the nominal axis (straight track):	Without pilot jacking		
Combination coefficient for pipe's angular deflection:	ψ	0.80	[-]
Specification of thrust force:	No		
Free input of safety coefficient for the longitudinal direction:	No		
Monitored installation:	No		

1.1.3 Pressure transfer ring (PTR)

Kind of thrust transfer:	Without pressure transfer ring

1.1.4 Soil mechanical values

Soil conditions:	Granular soil
Soil group around pipe:	G1
Different soil group above pipe:	No
Bedding angle (granular soil):	2α = 180° (standard case)
Manuel definition inner friction of soil:	No
Manual entering of specific weight of soil:	No

1.1.5 Soil

Manual specification of modulus of deformation of soil:	No
Application of silo theory:	Automatic
Manual specification of K1, δ and c:	No
Compactness of the packing around pipe:	Medium dense to dense

Taking concentration factor λF in account:	No		

1.1.6 Loadings

Cover height:	h	2.0	m
Additional surface load:	P_0	0.00	kN/m²
Partial safety factor for outer water pressure:	$\gamma_{F,W}$	1.35	[-]
Groundwater level above pipe invert:	h_{GW}	0.0	m
Inner pressure (operational state):	$P_{I,O}$	0.0	bar
Pipe is filled with liquid during operation:	No		
Free input of safty factor for traffic load:	No		
Traffic load:	Rail Traffic Load LM71, single track		
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Manuell definition reduction ratio for dynamic load:	No		

1.1.7 Calculation options

Buckling proof:	According to A 127
Deformation proof:	According to A 161
Admissible deflection according A161:	Yes
Dynamic proof:	Use standard
Minimum sectional forces according standard:	Yes
Comparison stress minimum sectional forces:	Use design values

1.1.8 Solid/profiled pipes

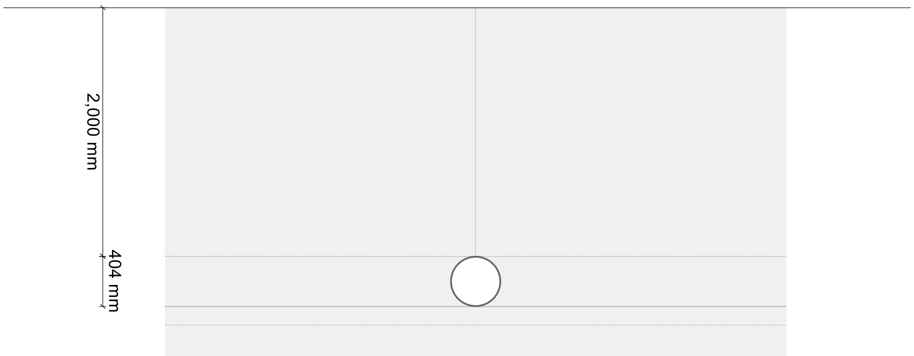
Pipe choice:	Solid wall		
Material class:	Metals		
A type predeformation:	$\delta_{v,TypA}$	1.0	%
Local deformation:	$\delta_{v,lokal}$	0.0	%
Choice of input:	Do and s		
Outer diameter:	d_a	404.0	mm
Wall thickness:	s	10.0	mm
Perforation:	No perforation		
Outer offset:	$\Delta d_{a,min}$	0.0	mm
Internal offset:	$\Delta d_{i,max}$	0.0	mm
Pipe length:	L_R	3.00	m
Manual value for ∆acal:	No		
Pipe end is pre-stressed:	No		
Eccentricity at pipe connection:	vorh e	0.0	mm

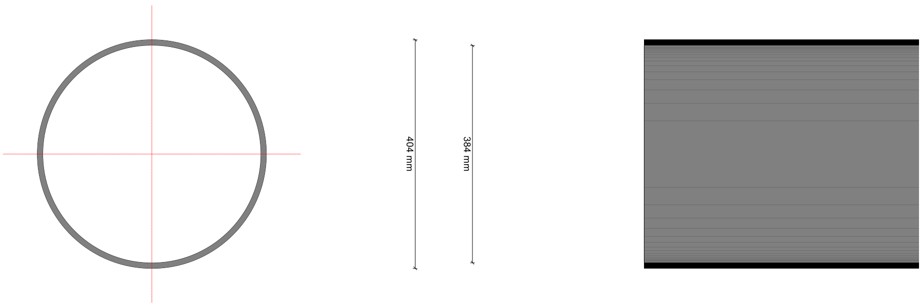
1.1.8.1 Metal

Partial safety coefficient according to standard:	Yes
Choice material:	According to DIN (German standard)
Dyn. Nachweis führen nach:	Regelwerk
Kerbfall nach EC 3-1-9, Bild 7.1:	71
Steel quality DIN:	Steel S235 (EN 10025-2)
Use cross-sectional plastic reserves:	No
Indication of ultimate hoop tensile stress:	Yes
Metal type:	Steel- (ZM), welded pipes

1.1.8.2 System drawing

Rail Traffic Load LM71, single track





1.2 Results

1.2.1 Partial safety coefficients (impacts)

Partial safety factor for non-static loads (traffic loads), radial:	γ_Q	1.35	[-]
Partial safety coefficient for inner pressure (pressure pipes > 0,5 bar):	$\gamma_{F,Pi}$	1.50	[-]
Partial safety factor for static loads, radial:	γ_F	1.35	[-]
Partial safety factor for loads, longitudinal:	$\gamma_{F,ax}$	1.30	[-]

1.2.2 Intermediate results pipe

Inner diameter:	d_i	384.0	mm
Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm
Ratio radius to wall thickness:	r_m/s	19.700	[-]
Curve correction factor, internal:	α_{ki}	1.000	[-]
Curve correction factor, external:	α_{ka}	1.000	[-]
Local predeformation:	δ_{vl}	0.00	%
Predeformation (ovalisation before load):	δ_{vg}	1.00	%
Axially effected profile surface:	A_{ax}	10.00	mm²/mm
Radial cross section:	A_{rad}	10.00	mm²/mm
Distance of inertia:	e	5.00	mm
Moment of inertia:	I	83.33	mm^4/mm
Outer moment of resistance:	W_a	16.67	mm³/mm
Inner moment of resistance:	W_i	16.67	mm³/mm
Surface ratio:	κ_Q	1.2	[-]
Minimum outer diameter:	$d_{a,min}$	404	mm
Maximum inner diameter:	$d_{i,max}$	384	mm
Max. difference of rectangularity concerning the face surface:	$\Delta_{a,cal}$	3.2	mm
Length of the single jacking pipe:	L_R	3.00	m

1.2.2.1 Material properties

Specific gravity:	γ_R	78.5	kN/m³
Poissons ratio:	v	0.30	[-]
Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of Young's modulus in axial direction:	$E_{R,ax}$	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	235.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	235.0	N/mm²
Characteristic value of hoop tensile strength:	σ_{RZ}	235.0	N/mm²
Amplitude for 2·10^6 load cycles:	$2\sigma_{a,2E6}$	71.0	N/mm²
Schwingbreite bei 5·10^6 Lastspielen:	$2\sigma_{a,5E6}$	52.3	N/mm²
Amplitude for 1·10^8 cycles:	$2\sigma_{a,1E8}$	28.8	N/mm²
Characteristic value of axial compressive strength:	σ_{LD}	235.0	N/mm²

1.2.2.2 Safety factors

Local security coifficient for component friction longitudinal to pipe axis:	$\gamma_{M,ax}$	1.35	[-]
Local security coifficient for component friction lateral to pipe axis:	$\gamma_{M,rad}$	1.10	[-]
Local security coifficient for component friction longitudinal on stability:	$\gamma_{M,stab}$	1.85	[-]
Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]

1.2.2.3 Checking of the minimum wallthickness

Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm

Calculated minimum wallthickness:	min. t	6.30	mm

The wall thickness is equal to or greater than the minimum wall thickness according to A161 9.3.1 table 19/20!

1.2.3 Intermediate results for the soil

Specific weight of soil:	γ_B	20.0	kN/m³
Buoyant weight of soil:	γ'_B	11.0	kN/m³
Soil group around pipe:	G1		
Angle of inner friction around pipe:	φ'_2	32.5	°
Basis value of modulus of deformation of soil:	E_0	50.00	N/mm²
Coefficient for the compactness of the packing/consistency according A161 table 3/4:	f_1	0.60	[-]
Loosening coefficient caused by jacking according to A161, table 5.:	f_2	0.80	[-]
Angle of inner friction above pipe:	φ'_1	32.5	°
Stress exponent:	z	0.4	[-]
Remarks concerning silo theory:	κ = 1 as there is no dislocation of earth.		
The consideration of concentration factor λF is necessary.:	Yes		
Concentration factor:	λ	1.000	[-]
Base value of earth pressure ratio below crown:	$K_{2,0}$	0.46	[-]
Earth pressure ratio above pipe, construction state:	$K_{2,Bau}$	0.37	[-]
Earth pressure ratio above pipe, operational state:	$K_{2,End}$	0.46	[-]

1.2.4 Operational state

1.2.4.1 Loads Operational state

Impact factor:	Φ_2	1.67	[-]
Impact factor:	red Φ_2	1.57	[-]
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Basic vertical soil stress due to traffic load:	p	43.50	kN/m²
Vertical soil stress at crown height due to traffic load:	p_T	68.30	kN/m²
Vertical soil stresses due to traffic load at springline (without impact factor φ):	p_K	41.68	kN/m²
Earth pressure ratio below crown:	K_2	0.46	[-]
Horizontal soil stress due to traffic load:	$p_{T,h}$	24.78	kN/m²
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Effective vertical stress at pipe crown level:	q_{Ev}	40.000	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Distribution of earth pressure at the pipe is assumed to be cos²- or sin²-shaped.:	No		
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Inner gauge pressure:	p_i	0.000	bar
Outer gauge pressure above pipe crown:	$p_{a,Sc}$	0.000	bar
Pipe stiffness:	S_R	2,289	kN/m²
Pipe stiffness:	$\bar{S}_R$	2,289	kN/m²
Scaling reference value:	$\sigma_{B,0}$	100.0	kN/m²
Increase factor due to soil stress:	f_3	1.00	[-]
Modulus of deformation of soil:	E_B	24.00	N/mm²
Earth pressure ratio below crown:	K_2	0.46	[-]
Stiffness of bedding:	S_{Bh}	14.40	N/mm²
System stiffness:	V_{RB}	0.1590	[-]
The pipe soil system is rated flexible:	Yes		

According to DWA-A 161, chapter 6.2.2, the lateral bedding reaction pressure may be applied only if the pipe remains permanently and completely grouted after the jacking is finished.

1.2.4.2 Section forces Operational state

Moments:		crown	springline	invert	
Vertical load due to earth coverage	$M_{pEv,d}$	0.524	-0.524	0.524	kNm/m
Vertical load due to traffic load	$M_{pTv,d}$	0.895	-0.895	0.895	kNm/m
Horizontal load due to traffic	$M_{pTh,d}$	-0.325	0.325	-0.325	kNm/m
Horizontal load due to earth coverage	$M_{pEh,d}$	-0.267	0.267	-0.267	kNm/m
Dead weight	$M_{g,d}$	0.016	-0.018	0.029	kNm/m
Waterfilling upto crown	$M_{w,d}$	0.000	0.000	0.000	kNm/m
Bouyancy (outer water level upto crown)	$M_{a,d}$	0.000	0.000	0.000	kNm/m
Water pressure	$M_{pw,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure due to earth load	$M_{qEh*,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure	$M_{qh*,d}$	0.000	0.000	0.000	kNm/m
Sum of moments	ΣM_d	0.843	-0.845	0.856	kNm/m

Normal forces:		crown	springline	invert	
Vertical load due to earth coverage	$N_{pEv,d}$	0.000	-10.638	0.000	kN/m
Vertical load due to traffic	$N_{pTv,d}$	0.000	-18.163	0.000	kN/m
Horizontal load due to traffic	$N_{pTh,d}$	-6.591	0.000	-6.591	kN/m
Horizontal load due to earth coverage	$N_{pEh,d}$	-5.419	0.000	-5.419	kN/m
Dead weight	$N_{g,d}$	0.052	-0.328	-0.298	kN/m
Waterfilling upto crown	$N_{w,d}$	0.000	0.000	0.000	kN/m
Bouyancy (outer groundwater level upto crown)	$N_{a,d}$	0.000	0.000	0.000	kN/m
Water pressure	$N_{pw,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to earth load	$N_{qEh*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to traffic load	$N_{qTh*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure	$N_{qh*,d}$	0.000	0.000	0.000	kN/m
Sum of normal forces	ΣN_d	-11.958	-29.129	-12.308	kN/m

1.2.4.3 Deflection proof Operational state

Deflection coeffizient:	$c_{v,qh*}$	0.0640	[-]
Deflection coeffizient:	$c_{v,qv}$	-0.0833	[-]
Coefficient of bedding reaction pressure:	K^*	0.371	[-]
Deflection coefficient:	c^*_v	-0.060	[-]
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Vertical soil stress due to traffic load:	p_T	68.30	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Horizontal soil stress due to traffic load:	p_{Th}	24.78	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Relative vertical change of diameter:	δ_V	0.16	%
Admissible change of vertical diameter:	zul δ_V	2.00	%
Utilisation factor deflection:	$U_{\delta V}$	8.2	%

The calculated deflection is less than the admissible deflection.

1.2.4.4 Buckling proof Operational state

Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]
Total vertical load, design value:	$q_{v,d}$	146.20	kN/m²
Reduction factor for critical vertical load (acc. A127):	κ_{v2}	0.85	[-]
Critical earth load:	krit $q_{v,d}$	6.871	N/mm²

$$\text{krit } q_{v,d} = \kappa_{v2} \cdot \left(3 + \frac{1}{3\, V_{RB}}\right) \cdot S_R \cdot \frac{1}{\gamma_{M,stab,red}} \qquad (72b)$$

Utilisation factor stability (total vertical load):	U_{qv}	2.1	%
Outer gauge pressure, invert:	$p_{a,So}$	0.000	bar

Maximum external pressure due to water, supporting aids or lubricant, forge pressure:	$p_{a,max}$	0.000	bar
Outer hydrostatic pressure, design value:	$p_{a,d}$	0.00	bar

The buckling proof due to water pressure is not necessary, because there is neither ground water nor depression.

Utilisation factor stability:	$U_{Stab,rad}$	2.1	%

The proof of stability is provided.

1.2.4.5 Stress proof Operational state

Inside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \qquad (54)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	48.415	-52.497	48.415	N/mm²

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \qquad (54)$$

		crown	springline	invert	
Stress due to other loads	$\sigma_{re,d}$	0.953	-1.111	1.712	N/mm²
Total stress	σ	49.368	-53.608	50.128	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	23.1	---	23.5	%
Utilisation flexural compression:	U_{BD}	---	25.1	---	%

Outside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \qquad (55)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	-50.818	46.736	-50.818	N/mm²

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \qquad (55)$$

		crown	springline	invert	
Stress due to other loads	$\sigma_{re,d}$	-0.942	1.046	-1.772	N/mm²
Total stress	σ	-51.760	47.782	-52.590	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	---	22.4	---	%
Utilisation flexural compression:	U_{BD}	24.2	---	24.6	%

All calculated stresses are smaller than the admissible values.

1.2.4.6 Proof of safety against failure with not predominantly static loading

Vertical relevant dynamic pressure in crown level:	dyn p_T	68.30	kN/m²
Horizontal soil stresses due to traffic load for fatigue proof:	$p_{Th,E}$	24.78	kN/m²
Horizontal earth pressure due to traffic load to be considered:	dyn p_{Th}	24.8	kN/m²

The supporting effect of the bedding reaction pressure dyn pVh* is not applied, as the pipe-soil-system is not rated as flexible.

		crown	springline	invert	
Normal force due to vertical traffic load	dyn N_{pTv}	0.000	-13.454	0.000	kN/m
Normal force due to horizontal traffic load	dyn N_{pTh}	-4.882	0.000	-4.882	kN/m
Sum of normal forces due to traffic load	dyn ΣN	-4.882	-13.454	-4.882	kN/m
Moment due to vertical traffic load	dyn M_{pTv}	0.663	-0.663	0.663	kNm/m
Moment due to horizontal traffic load	dyn M_{pTh}	-0.240	0.240	-0.240	kNm/m
Sum of moments due to traffic load	dyn ΣM	0.422	-0.422	0.422	kNm/m

Sum of moments due to static loads	ΣM_g	0.202	-0.204	0.212	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.976	-8.123	-4.235	kN/m

Schwingbreite bei 5·10^6 Lastspielen:			$2\sigma_{a,5E6}$	52.327	N/mm²
Inside					
Curve correction factor, internal:			α_{ki}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	24.842	-26.675	24.842	N/mm²
Utilisation factor dynamic stress component	dyn U	52.2	---	52.2	%
outside					
Curve correction factor, external:			α_{ka}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	-25.818	23.985	-25.818	N/mm²
Utilisation factor dynamic stress component	dyn U	---	50.4	---	%

The proof of safety against failure with not predominantly static loading is provided.

All necessary proofs are ok.

2 Jacking pipe according to DWA-A 161, 2nd edition: hü = 2 m DWA Tab. 22

Correction sheet dated May 2017 is considered.

Caption of this part of the calculation:	hü = 2 m DWA Tab. 22
Assumptions:	Überdeckungshöhe > 1,5 m 5x10^6 anwendbar, jedoch Ansazt nach Tabelle 22 des DWA-A 161 gewählt (VERALTET!)

Kind of calculation:	Solid wall
States to be calculated:	Only operational state
Add sketch to print:	Yes
Print minimum sectional forces in operational state:	Yes

2.1 Input

2.1.1 Jacking method

Dynamic jacking pipe:	No
Method:	Manual input
Kind of soil dislocation:	None
Complete and permanent grouting of the annular gap:	No
Using of proppant or lubricant:	No
Annular gap:	Other jacking techniques, continous support of annular gap with documentation

2.1.2 Routing and jacking force

Jacking route:	Straight line		
Calculation of the unplanned deviations from the nominal axis (straight track):	Without pilot jacking		
Combination coefficient for pipe's angular deflection:	ψ	0.80	[-]
Specification of thrust force:	No		
Free input of safety coefficient for the longitudinal direction:	No		
Monitored installation:	No		

2.1.3 Pressure transfer ring (PTR)

Kind of thrust transfer:	Without pressure transfer ring

2.1.4 Soil mechanical values

Soil conditions:	Granular soil
Soil group around pipe:	G1
Different soil group above pipe:	No
Bedding angle (granular soil):	2α = 180° (standard case)
Manuel definition inner friction of soil:	No
Manual entering of specific weight of soil:	No

2.1.5 Soil

Manual specification of modulus of deformation of soil:	No
Application of silo theory:	Automatic
Manual specification of K1, δ and c:	No
Compactness of the packing around pipe:	Medium dense to dense
Taking concentration factor λF in account:	No

2.1.6 Loadings

Cover height:	h	2.0	m
Additional surface load:	P_0	0.00	kN/m²
Partial safety factor for outer water pressure:	$\gamma_{F,W}$	1.35	[-]
Groundwater level above pipe invert:	h_{GW}	0.0	m
Inner pressure (operational state):	$P_{I,O}$	0.0	bar
Pipe is filled with liquid during operation:	No		
Free input of safty factor for traffic load:	No		
Traffic load:	Rail Traffic Load LM71, single track		
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Manuell definition reduction ratio for dynamic load:	No		

2.1.7 Calculation options

Buckling proof:	According to A 127
Deformation proof:	According to A 161
Admissible deflection according A161:	Yes
Dynamic proof:	Use standard
Minimum sectional forces according standard:	Yes
Comparison stress minimum sectional forces:	Use design values

2.1.8 Solid/profiled pipes

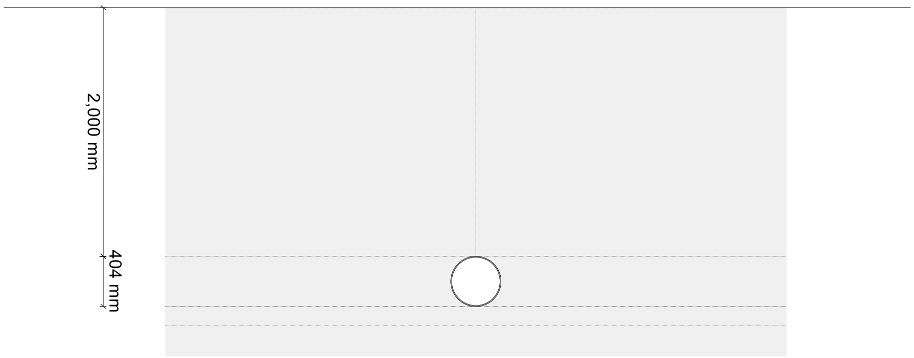
Pipe choice:	Solid wall		
Material class:	Metals		
A type predeformation:	$\delta_{v,TypA}$	1.0	%
Local deformation:	$\delta_{v,lokal}$	0.0	%
Choice of input:	Do and s		
Outer diameter:	d_a	404.0	mm
Wall thickness:	s	10.0	mm
Perforation:	No perforation		
Outer offset:	$\Delta d_{a,min}$	0.0	mm
Internal offset:	$\Delta d_{i,max}$	0.0	mm
Pipe length:	L_R	3.00	m
Manual value for ∆acal:	No		
Pipe end is pre-stressed:	No		
Eccentricity at pipe connection:	vorh e	0.0	mm

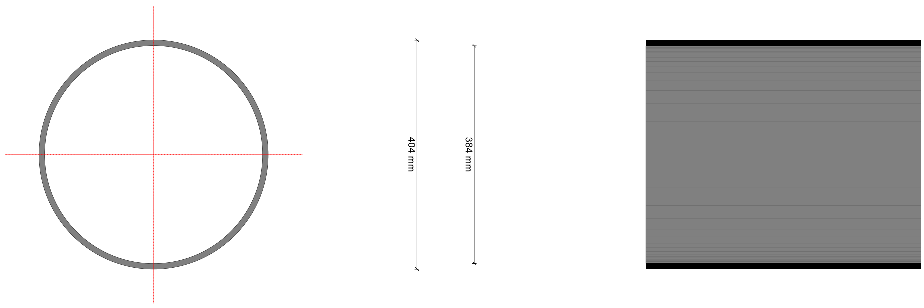
2.1.8.1 Metal

Partial safety coefficient according to standard:	Yes
Choice material:	According to DIN (German standard)
Dyn. Nachweis führen nach:	DWA-A 161 Tab. 22
Steel quality DIN:	Steel S235 (EN 10025-2)
Use cross-sectional plastic reserves:	No
Indication of ultimate hoop tensile stress:	Yes
Metal type:	Steel- (ZM), welded pipes

2.1.8.2 System drawing

Rail Traffic Load LM71, single track





2.2 Results

2.2.1 Partial safety coefficients (impacts)

Partial safety factor for non-static loads (traffic loads), radial:	γ_Q	1.35	[-]
Partial safety coefficient for inner pressure (pressure pipes > 0,5 bar):	$\gamma_{F,Pi}$	1.50	[-]
Partial safety factor for static loads, radial:	γ_F	1.35	[-]
Partial safety factor for loads, longitudinal:	$\gamma_{F,ax}$	1.30	[-]

2.2.2 Intermediate results pipe

Inner diameter:	d_i	384.0	mm
Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm
Ratio radius to wall thickness:	r_m/s	19.700	[-]
Curve correction factor, internal:	α_{ki}	1.000	[-]
Curve correction factor, external:	α_{ka}	1.000	[-]
Local predeformation:	δ_{vl}	0.00	%
Predeformation (ovalisation before load):	δ_{vg}	1.00	%
Axially effected profile surface:	A_{ax}	10.00	mm²/mm
Radial cross section:	A_{rad}	10.00	mm²/mm
Distance of inertia:	e	5.00	mm
Moment of inertia:	I	83.33	mm^4/mm
Outer moment of resistance:	W_a	16.67	mm³/mm
Inner moment of resistance:	W_i	16.67	mm³/mm
Surface ratio:	κ_Q	1.2	[-]
Minimum outer diameter:	$d_{a,min}$	404	mm
Maximum inner diameter:	$d_{i,max}$	384	mm
Max. difference of rectangularity concerning the face surface:	$\Delta_{a,cal}$	3.2	mm
Length of the single jacking pipe:	L_R	3.00	m

2.2.2.1 Material properties

Specific gravity:	γ_R	78.5	kN/m³
Poissons ratio:	v	0.30	[-]
Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of Young's modulus in axial direction:	$E_{R,ax}$	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	235.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	235.0	N/mm²
Characteristic value of hoop tensile strength:	σ_{RZ}	235.0	N/mm²
Amplitude for 2·10^6 load cycles:	$2\sigma_{a,2E6}$	71.0	N/mm²
Schwingbreite bei 5·10^6 Lastspielen:	$2\sigma_{a,5E6}$	52.3	N/mm²
Amplitude for 1·10^8 cycles:	$2\sigma_{a,1E8}$	28.8	N/mm²
Characteristic value of axial compressive strength:	σ_{LD}	235.0	N/mm²

2.2.2.2 Safety factors

Local security coifficient for component friction longitudinal to pipe axis:	$\gamma_{M,ax}$	1.35	[-]
Local security coifficient for component friction lateral to pipe axis:	$\gamma_{M,rad}$	1.10	[-]
Local security coifficient for component friction longitudinal on stability:	$\gamma_{M,stab}$	1.85	[-]
Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]

2.2.2.3 Checking of the minimum wallthickness

Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm

Calculated minimum wallthickness:	min. t	6.30	mm

The wall thickness is equal to or greater than the minimum wall thickness according to A161 9.3.1 table 19/20!

2.2.3 Intermediate results for the soil

Specific weight of soil:	γ_B	20.0	kN/m³
Buoyant weight of soil:	γ'_B	11.0	kN/m³
Soil group around pipe:	G1		
Angle of inner friction around pipe:	φ'_2	32.5	°
Basis value of modulus of deformation of soil:	E_0	50.00	N/mm²
Coefficient for the compactness of the packing/consistency according A161 table 3/4:	f_1	0.60	[-]
Loosening coefficient caused by jacking according to A161, table 5.:	f_2	0.80	[-]
Angle of inner friction above pipe:	φ'_1	32.5	°
Stress exponent:	z	0.4	[-]
Remarks concerning silo theory:	κ = 1 as there is no dislocation of earth.		
The consideration of concentration factor λF is necessary.:	Yes		
Concentration factor:	λ	1.000	[-]
Base value of earth pressure ratio below crown:	$K_{2,0}$	0.46	[-]
Earth pressure ratio above pipe, construction state:	$K_{2,Bau}$	0.37	[-]
Earth pressure ratio above pipe, operational state:	$K_{2,End}$	0.46	[-]

2.2.4 Operational state

2.2.4.1 Loads Operational state

Impact factor:	Φ_2	1.67	[-]
Impact factor:	red Φ_2	1.57	[-]
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Basic vertical soil stress due to traffic load:	p	43.50	kN/m²
Vertical soil stress at crown height due to traffic load:	p_T	68.30	kN/m²
Vertical soil stresses due to traffic load at springline (without impact factor φ):	p_K	41.68	kN/m²
Earth pressure ratio below crown:	K_2	0.46	[-]
Horizontal soil stress due to traffic load:	$p_{T,h}$	24.78	kN/m²
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Effective vertical stress at pipe crown level:	q_{Ev}	40.000	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Distribution of earth pressure at the pipe is assumed to be cos²- or sin²-shaped.:	No		
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Inner gauge pressure:	p_i	0.000	bar
Outer gauge pressure above pipe crown:	$p_{a,Sc}$	0.000	bar
Pipe stiffness:	S_R	2,289	kN/m²
Pipe stiffness:	$\bar{S}_R$	2,289	kN/m²
Scaling reference value:	$\sigma_{B,0}$	100.0	kN/m²
Increase factor due to soil stress:	f_3	1.00	[-]
Modulus of deformation of soil:	E_B	24.00	N/mm²
Earth pressure ratio below crown:	K_2	0.46	[-]
Stiffness of bedding:	S_{Bh}	14.40	N/mm²
System stiffness:	V_{RB}	0.1590	[-]
The pipe soil system is rated flexible:	Yes		

According to DWA-A 161, chapter 6.2.2, the lateral bedding reaction pressure may be applied only if the pipe remains permanently and completely grouted after the jacking is finished.

2.2.4.2 Section forces Operational state

Moments:		crown	springline	invert	
Vertical load due to earth coverage	$M_{pEv,d}$	0.524	-0.524	0.524	kNm/m
Vertical load due to traffic load	$M_{pTv,d}$	0.895	-0.895	0.895	kNm/m
Horizontal load due to traffic	$M_{pTh,d}$	-0.325	0.325	-0.325	kNm/m
Horizontal load due to earth coverage	$M_{pEh,d}$	-0.267	0.267	-0.267	kNm/m
Dead weight	$M_{g,d}$	0.016	-0.018	0.029	kNm/m
Waterfilling upto crown	$M_{w,d}$	0.000	0.000	0.000	kNm/m
Bouyancy (outer water level upto crown)	$M_{a,d}$	0.000	0.000	0.000	kNm/m
Water pressure	$M_{pw,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure due to earth load	$M_{qEh^*,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure	$M_{qh^*,d}$	0.000	0.000	0.000	kNm/m
Sum of moments	ΣM_d	0.843	-0.845	0.856	kNm/m

Normal forces:		crown	springline	invert	
Vertical load due to earth coverage	$N_{pEv,d}$	0.000	-10.638	0.000	kN/m
Vertical load due to traffic	$N_{pTv,d}$	0.000	-18.163	0.000	kN/m
Horizontal load due to traffic	$N_{pTh,d}$	-6.591	0.000	-6.591	kN/m
Horizontal load due to earth coverage	$N_{pEh,d}$	-5.419	0.000	-5.419	kN/m
Dead weight	$N_{g,d}$	0.052	-0.328	-0.298	kN/m
Waterfilling upto crown	$N_{w,d}$	0.000	0.000	0.000	kN/m
Bouyancy (outer groundwater level upto crown)	$N_{a,d}$	0.000	0.000	0.000	kN/m
Water pressure	$N_{pw,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to earth load	$N_{qEh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to traffic load	$N_{qTh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure	$N_{qh^*,d}$	0.000	0.000	0.000	kN/m
Sum of normal forces	ΣN_d	-11.958	-29.129	-12.308	kN/m

2.2.4.3 Deflection proof Operational state

Deflection coeffizient:	c_{v,qh^*}	0.0640	[-]
Deflection coeffizient:	$c_{v,qv}$	-0.0833	[-]
Coefficient of bedding reaction pressure:	K^*	0.371	[-]
Deflection coefficient:	c^*_v	-0.060	[-]
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Vertical soil stress due to traffic load:	p_T	68.30	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Horizontal soil stress due to traffic load:	p_{Th}	24.78	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Relative vertical change of diameter:	δ_V	0.16	%
Admissible change of vertical diameter:	zul δ_V	2.00	%
Utilisation factor deflection:	$U_{\delta V}$	8.2	%

The calculated deflection is less than the admissible deflection.

2.2.4.4 Buckling proof Operational state

Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]
Total vertical load, design value:	$q_{v,d}$	146.20	kN/m²
Reduction factor for critical vertical load (acc. A127):	κ_{v2}	0.85	[-]
Critical earth load:	krit $q_{v,d}$	6.871	N/mm²

$$\text{krit } q_{v,d} = \kappa_{v2} \cdot \left\{ 3 + \frac{1}{3\,V_{RB}} \right\} \cdot S_R \cdot \frac{1}{\gamma_{M,stab,red}} \qquad (72b)$$

Utilisation factor stability (total vertical load):	U_{qv}	2.1	%
Outer gauge pressure, invert:	$p_{a,So}$	0.000	bar

Maximum external pressure due to water, supporting aids or lubricant, forge pressure:	$p_{a,max}$	0.000	bar
Outer hydrostatic pressure, design value:	$p_{a,d}$	0.00	bar

The buckling proof due to water pressure is not necessary, because there is neither ground water nor depression.

Utilisation factor stability:	$U_{Stab,rad}$	2.1	%

The proof of stability is provided.

2.2.4.5 Stress proof Operational state

Inside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \quad (54)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \quad (54)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	48.415	-52.497	48.415	N/mm²
Stress due to other loads	$\sigma_{re,d}$	0.953	-1.111	1.712	N/mm²
Total stress	σ	49.368	-53.608	50.128	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	23.1	---	23.5	%
Utilisation flexural compression:	U_{BD}	---	25.1	---	%

Outside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \quad (55)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \quad (55)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	-50.818	46.736	-50.818	N/mm²
Stress due to other loads	$\sigma_{re,d}$	-0.942	1.046	-1.772	N/mm²
Total stress	σ	-51.760	47.782	-52.590	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	---	22.4	---	%
Utilisation flexural compression:	U_{BD}	24.2	---	24.6	%

All calculated stresses are smaller than the admissible values.

2.2.4.6 Proof of safety against failure with not predominantly static loading

Vertical relevant dynamic pressure in crown level:	dyn p_T	68.30	kN/m²
Horizontal soil stresses due to traffic load for fatigue proof:	$p_{Th,E}$	24.78	kN/m²
Horizontal earth pressure due to traffic load to be considered:	dyn p_{Th}	24.8	kN/m²

The supporting effect of the bedding reaction pressure dyn pVh* is not applied, as the pipe-soil-system is not rated as flexible.

		crown	springline	invert	
Normal force due to vertical traffic load	dyn N_{pTv}	0.000	-13.454	0.000	kN/m
Normal force due to horizontal traffic load	dyn N_{pTh}	-4.882	0.000	-4.882	kN/m
Sum of normal forces due to traffic load	dyn ΣN	-4.882	-13.454	-4.882	kN/m
Moment due to vertical traffic load	dyn M_{pTv}	0.663	-0.663	0.663	kNm/m
Moment due to horizontal traffic load	dyn M_{pTh}	-0.240	0.240	-0.240	kNm/m
Sum of moments due to traffic load	dyn ΣM	0.422	-0.422	0.422	kNm/m

Sum of moments due to static loads	ΣM_g	0.202	-0.204	0.212	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.976	-8.123	-4.235	kN/m

Inside

Curve correction factor, internal:			α_{ki}	1.000	[-]

The dynamic proof considers tensile stresses only, comprehensive stress are not examined.

Dynamic stress component	dyn σ_{pT}	24.842	-26.675	24.842	N/mm²
Sum of moments due to static loads	ΣM_g	0.202	-0.204	0.212	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.976	-8.123	-4.235	kN/m
Double stress amplitude	$\Delta\sigma_{Be}$	24.842	---	24.842	N/mm²
Stress due to static load	σ_g	11.727	---	12.290	N/mm²

$\max \sigma_{0,Be} = \max(|\sigma_g|;|\sigma_g + \Delta\sigma_{Be}|)$

Upper stress	$\max \sigma_{0,Be}$	36.569	---	37.132	N/mm²

$\min \sigma_{0,Be} = \min(|\sigma_g|;|\sigma_g + \Delta\sigma_{Be}|)$

Lower stress	$\min \sigma_{0,Be}$	11.727	---	12.290	N/mm²
Notch group	X_{Be}	0.321	---	0.331	[-]
Admissible double stress amplitude, Tab.22	zul $\Delta\sigma_{Be,T22}$	85.965	0.000	85.451	N/mm²

Table 22's value for the admissible double stress amplitude will be multiplied by the factor 0.405 for 2x10^8 cycles because Table 22's values are valid for 2x10^6 cycles only.

Admissible double stress amplitude	zul $\Delta\sigma_{Be}$	34.816	---	34.608	N/mm²
Utilisation factor double stress amplitude	dyn U	71.4	---	71.8	%

outside

Curve correction factor, external:			α_{ka}	1.000	[-]

The dynamic proof considers tensile stresses only, comprehensive stress are not examined.

Dynamic stress component	dyn σ_{pT}	-25.818	23.985	-25.818	N/mm²
Sum of moments due to static loads	ΣM_g	0.202	-0.204	0.212	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.976	-8.123	-4.235	kN/m
Double stress amplitude	$\Delta\sigma_{Be}$	---	23.985	---	N/mm²
Stress due to static load	σ_g	---	11.410	---	N/mm²

$\max \sigma_{0,Be} = \max(|\sigma_g|;|\sigma_g + \Delta\sigma_{Be}|)$

Upper stress	$\max \sigma_{0,Be}$	---	35.394	---	N/mm²

$\min \sigma_{0,Be} = \min(|\sigma_g|;|\sigma_g + \Delta\sigma_{Be}|)$

Lower stress	$\min \sigma_{0,Be}$	---	11.410	---	N/mm²
Notch group	X_{Be}	---	0.322	---	[-]
Admissible double stress amplitude, Tab.22	zul $\Delta\sigma_{Be,T22}$	0.000	85.882	0.000	N/mm²

Table 22's value for the admissible double stress amplitude will be multiplied by the factor 0.405 for 2x10^8 cycles because Table 22's values are valid for 2x10^6 cycles only.

Admissible double stress amplitude	zul $\Delta\sigma_{Be}$	---	34.782	---	N/mm²
Utilisation factor double stress amplitude	dyn U	---	69.0	---	%

The proof of safety against failure with not predominantly static loading is provided.

All necessary proofs are ok.

3 Jacking pipe according to DWA-A 161, 2nd edition: hü = 2 m Bahn TM

Correction sheet dated May 2017 is considered.

Caption of this part of the calculation:	hü = 2 m Bahn TM
Assumptions:	Überdeckungshöhe > 1,5 m 5x10^6 anwendbar Identisch mit der ersten Variante

Kind of calculation:	Solid wall
States to be calculated:	Only operational state
Add sketch to print:	Yes
Print minimum sectional forces in operational state:	Yes

3.1 Input

3.1.1 Jacking method

Dynamic jacking pipe:	No
Method:	Manual input
Kind of soil dislocation:	None
Complete and permanent grouting of the annular gap:	No
Using of proppant or lubricant:	No
Annular gap:	Other jacking techniques, continous support of annular gap with documentation

3.1.2 Routing and jacking force

Jacking route:	Straight line		
Calculation of the unplanned deviations from the nominal axis (straight track):	Without pilot jacking		
Combination coefficient for pipe's angular deflection:	ψ	0.80	[-]
Specification of thrust force:	No		
Free input of safety coefficient for the longitudinal direction:	No		
Monitored installation:	No		

3.1.3 Pressure transfer ring (PTR)

Kind of thrust transfer:	Without pressure transfer ring

3.1.4 Soil mechanical values

Soil conditions:	Granular soil
Soil group around pipe:	G1
Different soil group above pipe:	No
Bedding angle (granular soil):	$2\alpha = 180°$ (standard case)
Manuel definition inner friction of soil:	No
Manual entering of specific weight of soil:	No

3.1.5 Soil

Manual specification of modulus of deformation of soil:	No
Application of silo theory:	Automatic
Manual specification of K1, δ and c:	No
Compactness of the packing around pipe:	Medium dense to dense
Taking concentration factor λF in account:	No

3.1.6 Loadings

Cover height:	h	2.0	m
Additional surface load:	P_0	0.00	kN/m²
Partial safety factor for outer water pressure:	$\gamma_{F,W}$	1.35	[-]
Groundwater level above pipe invert:	h_{GW}	0.0	m
Inner pressure (operational state):	$P_{I,O}$	0.0	bar
Pipe is filled with liquid during operation:	No		
Free input of safty factor for traffic load:	No		
Traffic load:	Rail Traffic Load LM71, single track		
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Manuell definition reduction ratio for dynamic load:	No		

3.1.7 Calculation options

Buckling proof:	According to A 127
Deformation proof:	According to A 161
Admissible deflection according A161:	Yes
Dynamic proof:	Use standard
Minimum sectional forces according standard:	Yes
Comparison stress minimum sectional forces:	Use design values

3.1.8 Solid/profiled pipes

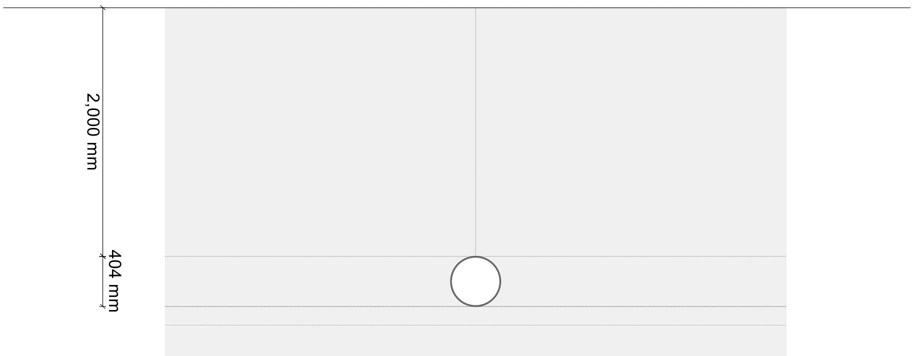
Pipe choice:	Solid wall		
Material class:	Metals		
A type predeformation:	$\delta_{v,TypA}$	1.0	%
Local deformation:	$\delta_{v,lokal}$	0.0	%
Choice of input:	Do and s		
Outer diameter:	d_a	404.0	mm
Wall thickness:	s	10.0	mm
Perforation:	No perforation		
Outer offset:	$\Delta d_{a,min}$	0.0	mm
Internal offset:	$\Delta d_{i,max}$	0.0	mm
Pipe length:	L_R	3.00	m
Manual value for ∆acal:	No		
Pipe end is pre-stressed:	No		
Eccentricity at pipe connection:	vorh e	0.0	mm

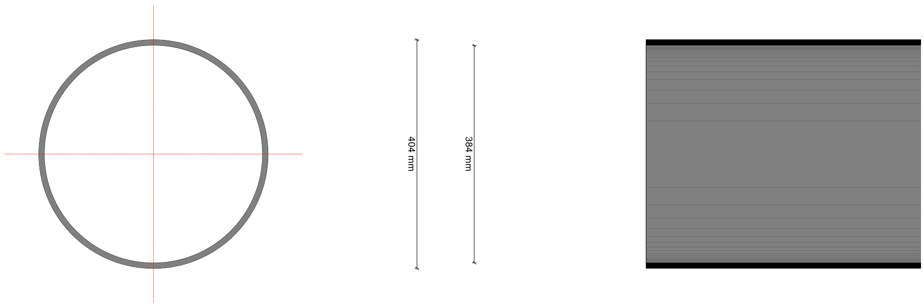
3.1.8.1 Metal

Partial safety coefficient according to standard:	Yes
Choice material:	According to DIN (German standard)
Dyn. Nachweis führen nach:	Bahn: TM 4-2019
Kerbfall nach EC 3-1-9, Bild 7.1:	71
Steel quality DIN:	Steel S235 (EN 10025-2)
Use cross-sectional plastic reserves:	No
Indication of ultimate hoop tensile stress:	Yes
Metal type:	Steel- (ZM), welded pipes

3.1.8.2 System drawing

Rail Traffic Load LM71, single track





3.2 Results

3.2.1 Partial safety coefficients (impacts)

Partial safety factor for non-static loads (traffic loads), radial:	γ_Q	1.35	[-]
Partial safety coefficient for inner pressure (pressure pipes > 0,5 bar):	$\gamma_{F,Pi}$	1.50	[-]
Partial safety factor for static loads, radial:	γ_F	1.35	[-]
Partial safety factor for loads, longitudinal:	$\gamma_{F,ax}$	1.30	[-]

3.2.2 Intermediate results pipe

Inner diameter:	d_i	384.0	mm
Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm
Ratio radius to wall thickness:	r_m/s	19.700	[-]
Curve correction factor, internal:	α_{ki}	1.000	[-]
Curve correction factor, external:	α_{ka}	1.000	[-]
Local predeformation:	δ_{vl}	0.00	%
Predeformation (ovalisation before load):	δ_{vg}	1.00	%
Axially effected profile surface:	A_{ax}	10.00	mm²/mm
Radial cross section:	A_{rad}	10.00	mm²/mm
Distance of inertia:	e	5.00	mm
Moment of inertia:	I	83.33	mm^4/mm
Outer moment of resistance:	W_a	16.67	mm³/mm
Inner moment of resistance:	W_i	16.67	mm³/mm
Surface ratio:	κ_Q	1.2	[-]
Minimum outer diameter:	$d_{a,min}$	404	mm
Maximum inner diameter:	$d_{i,max}$	384	mm
Max. difference of rectangularity concerning the face surface:	$\Delta_{a,cal}$	3.2	mm
Length of the single jacking pipe:	L_R	3.00	m

3.2.2.1 Material properties

Specific gravity:	γ_R	78.5	kN/m³
Poissons ratio:	v	0.30	[-]
Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of Young's modulus in axial direction:	$E_{R,ax}$	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	235.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	235.0	N/mm²
Characteristic value of hoop tensile strength:	σ_{RZ}	235.0	N/mm²
Amplitude for 2·10^6 load cycles:	$2\sigma_{a,2E6}$	71.0	N/mm²
Schwingbreite bei 5·10^6 Lastspielen:	$2\sigma_{a,5E6}$	52.3	N/mm²
Amplitude for 1·10^8 cycles:	$2\sigma_{a,1E8}$	28.8	N/mm²
Characteristic value of axial compressive strength:	σ_{LD}	235.0	N/mm²

3.2.2.2 Safety factors

Local security coifficient for component friction longitudinal to pipe axis:	$\gamma_{M,ax}$	1.35	[-]
Local security coifficient for component friction lateral to pipe axis:	$\gamma_{M,rad}$	1.10	[-]
Local security coifficient for component friction longitudinal on stability:	$\gamma_{M,stab}$	1.85	[-]
Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]

3.2.2.3 Checking of the minimum wallthickness

Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm

Calculated minimum wallthickness:	min. t	6.30	mm

The wall thickness is equal to or greater than the minimum wall thickness according to A161 9.3.1 table 19/20!

3.2.3 Intermediate results for the soil

Specific weight of soil:	γ_B	20.0	kN/m³
Buoyant weight of soil:	γ'_B	11.0	kN/m³
Soil group around pipe:	G1		
Angle of inner friction around pipe:	φ'_2	32.5	°
Basis value of modulus of deformation of soil:	E_0	50.00	N/mm²
Coefficient for the compactness of the packing/consistency according A161 table 3/4:	f_1	0.60	[-]
Loosening coefficient caused by jacking according to A161, table 5.:	f_2	0.80	[-]
Angle of inner friction above pipe:	φ'_1	32.5	°
Stress exponent:	z	0.4	[-]
Remarks concerning silo theory:	κ = 1 as there is no dislocation of earth.		
The consideration of concentration factor λF is necessary.:	Yes		
Concentration factor:	λ	1.000	[-]
Base value of earth pressure ratio below crown:	$K_{2,0}$	0.46	[-]
Earth pressure ratio above pipe, construction state:	$K_{2,Bau}$	0.37	[-]
Earth pressure ratio above pipe, operational state:	$K_{2,End}$	0.46	[-]

3.2.4 Operational state

3.2.4.1 Loads Operational state

Impact factor:	Φ_2	1.67	[-]
Impact factor:	red Φ_2	1.57	[-]
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Basic vertical soil stress due to traffic load:	p	43.50	kN/m²
Vertical soil stress at crown height due to traffic load:	p_T	68.30	kN/m²
Vertical soil stresses due to traffic load at springline (without impact factor φ):	p_K	41.68	kN/m²
Earth pressure ratio below crown:	K_2	0.46	[-]
Horizontal soil stress due to traffic load:	$p_{T,h}$	24.78	kN/m²
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Effective vertical stress at pipe crown level:	q_{Ev}	40.000	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Distribution of earth pressure at the pipe is assumed to be cos²- or sin²-shaped.:	No		
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Inner gauge pressure:	p_i	0.000	bar
Outer gauge pressure above pipe crown:	$p_{a,Sc}$	0.000	bar
Pipe stiffness:	S_R	2,289	kN/m²
Pipe stiffness:	$\overline{S}_R$	2,289	kN/m²
Scaling reference value:	$\sigma_{B,0}$	100.0	kN/m²
Increase factor due to soil stress:	f_3	1.00	[-]
Modulus of deformation of soil:	E_B	24.00	N/mm²
Earth pressure ratio below crown:	K_2	0.46	[-]
Stiffness of bedding:	S_{Bh}	14.40	N/mm²
System stiffness:	V_{RB}	0.1590	[-]
The pipe soil system is rated flexible:	Yes		

According to DWA-A 161, chapter 6.2.2, the lateral bedding reaction pressure may be applied only if the pipe remains permanently and completely grouted after the jacking is finished.

3.2.4.2 Section forces Operational state

Moments:		crown	springline	invert	
Vertical load due to earth coverage	$M_{pEv,d}$	0.524	-0.524	0.524	kNm/m
Vertical load due to traffic load	$M_{pTv,d}$	0.895	-0.895	0.895	kNm/m
Horizontal load due to traffic	$M_{pTh,d}$	-0.325	0.325	-0.325	kNm/m
Horizontal load due to earth coverage	$M_{pEh,d}$	-0.267	0.267	-0.267	kNm/m
Dead weight	$M_{g,d}$	0.016	-0.018	0.029	kNm/m
Waterfilling upto crown	$M_{w,d}$	0.000	0.000	0.000	kNm/m
Bouyancy (outer water level upto crown)	$M_{a,d}$	0.000	0.000	0.000	kNm/m
Water pressure	$M_{pw,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure due to earth load	$M_{qEh^*,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure	$M_{qh^*,d}$	0.000	0.000	0.000	kNm/m
Sum of moments	ΣM_d	0.843	-0.845	0.856	kNm/m

Normal forces:		crown	springline	invert	
Vertical load due to earth coverage	$N_{pEv,d}$	0.000	-10.638	0.000	kN/m
Vertical load due to traffic	$N_{pTv,d}$	0.000	-18.163	0.000	kN/m
Horizontal load due to traffic	$N_{pTh,d}$	-6.591	0.000	-6.591	kN/m
Horizontal load due to earth coverage	$N_{pEh,d}$	-5.419	0.000	-5.419	kN/m
Dead weight	$N_{g,d}$	0.052	-0.328	-0.298	kN/m
Waterfilling upto crown	$N_{w,d}$	0.000	0.000	0.000	kN/m
Bouyancy (outer groundwater level upto crown)	$N_{a,d}$	0.000	0.000	0.000	kN/m
Water pressure	$N_{pw,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to earth load	$N_{qEh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to traffic load	$N_{qTh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure	$N_{qh^*,d}$	0.000	0.000	0.000	kN/m
Sum of normal forces	ΣN_d	-11.958	-29.129	-12.308	kN/m

3.2.4.3 Deflection proof Operational state

Deflection coeffizient:	c_{v,qh^*}	0.0640	[-]
Deflection coeffizient:	$c_{v,qv}$	-0.0833	[-]
Coefficient of bedding reaction pressure:	K^*	0.371	[-]
Deflection coefficient:	c^*_v	-0.060	[-]
Vertical soil stress at crown level:	p_{Ev}	40.000	kN/m²
Vertical soil stress due to traffic load:	p_T	68.30	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	108.295	kN/m²
Horizontal soil stress at pipe:	q_{Eh}	20.38	kN/m²
Horizontal soil stress due to traffic load:	p_{Th}	24.78	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	45.160	kN/m²
Relative vertical change of diameter:	δ_V	0.16	%
Admissible change of vertical diameter:	zul δ_V	2.00	%
Utilisation factor deflection:	$U_{\delta V}$	8.2	%

The calculated deflection is less than the admissible deflection.

3.2.4.4 Buckling proof Operational state

Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]
Total vertical load, design value:	$q_{v,d}$	146.20	kN/m²
Reduction factor for critical vertical load (acc. A127):	κ_{v2}	0.85	[-]
Critical earth load:	krit $q_{v,d}$	6.871	N/mm²

$$\text{krit } q_{v,d} = \kappa_{v2} \cdot \left(3 + \frac{1}{3\ V_{RB}}\right) \cdot S_R \cdot \frac{1}{\gamma_{M,stab,red}} \quad (72b)$$

Utilisation factor stability (total vertical load):	U_{qv}	2.1	%
Outer gauge pressure, invert:	$p_{a,So}$	0.000	bar

Maximum external pressure due to water, supporting aids or lubricant, forge pressure:	$p_{a,max}$	0.000	bar
Outer hydrostatic pressure, design value:	$p_{a,d}$	0.00	bar

The buckling proof due to water pressure is not necessary, because there is neither ground water nor depression.

Utilisation factor stability:	$U_{Stab,rad}$	2.1	%

The proof of stability is provided.

3.2.4.5 Stress proof Operational state

Inside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \quad (54)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \quad (54)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	48.415	-52.497	48.415	N/mm²
Stress due to other loads	$\sigma_{re,d}$	0.953	-1.111	1.712	N/mm²
Total stress	σ	49.368	-53.608	50.128	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	23.1	---	23.5	%
Utilisation flexural compression:	U_{BD}	---	25.1	---	%

Outside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \quad (55)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \quad (55)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	-50.818	46.736	-50.818	N/mm²
Stress due to other loads	$\sigma_{re,d}$	-0.942	1.046	-1.772	N/mm²
Total stress	σ	-51.760	47.782	-52.590	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	---	22.4	---	%
Utilisation flexural compression:	U_{BD}	24.2	---	24.6	%

All calculated stresses are smaller than the admissible values.

3.2.4.6 Proof of safety against failure with not predominantly static loading

Vertical relevant dynamic pressure in crown level:	dyn p_T	68.30	kN/m²
Horizontal soil stresses due to traffic load for fatigue proof:	$p_{Th,E}$	24.78	kN/m²
Horizontal earth pressure due to traffic load to be considered:	dyn p_{Th}	24.8	kN/m²

The supporting effect of the bedding reaction pressure dyn pVh* is not applied, as the pipe-soil-system is not rated as flexible.

		crown	springline	invert	
Normal force due to vertical traffic load	dyn N_{pTv}	0.000	-13.454	0.000	kN/m
Normal force due to horizontal traffic load	dyn N_{pTh}	-4.882	0.000	-4.882	kN/m
Sum of normal forces due to traffic load	dyn ΣN	-4.882	-13.454	-4.882	kN/m
Moment due to vertical traffic load	dyn M_{pTv}	0.663	-0.663	0.663	kNm/m
Moment due to horizontal traffic load	dyn M_{pTh}	-0.240	0.240	-0.240	kNm/m
Sum of moments due to traffic load	dyn ΣM	0.422	-0.422	0.422	kNm/m

Sum of moments due to static loads	ΣM_g	0.202	-0.204	0.212	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.976	-8.123	-4.235	kN/m

Schwingbreite bei 5·10^6 Lastspielen:			$2\sigma_{a,5E6}$	52.327	N/mm²
Inside					
Curve correction factor, internal:			α_{ki}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	24.842	-26.675	24.842	N/mm²
Utilisation factor dynamic stress component	dyn U	52.2	---	52.2	%
outside					
Curve correction factor, external:			α_{ka}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	-25.818	23.985	-25.818	N/mm²
Utilisation factor dynamic stress component	dyn U	---	50.4	---	%

The proof of safety against failure with not predominantly static loading is provided.

All necessary proofs are ok.

4 Jacking pipe according to DWA-A 161, 2nd edition: hü = 1,2 m

Correction sheet dated May 2017 is considered.

Caption of this part of the calculation:	hü = 1,2 m
Assumptions:	Überdeckungshöhe < 1,5 m 5x10^6 NICHT anwendbar --> Hinweis auf der Oberfläche

Kind of calculation:	Solid wall
States to be calculated:	Only operational state
Add sketch to print:	Yes
Print minimum sectional forces in operational state:	Yes

4.1 Input

4.1.1 Jacking method

Dynamic jacking pipe:	No
Method:	Manual input
Kind of soil dislocation:	None
Complete and permanent grouting of the annular gap:	No
Using of proppant or lubricant:	No
Annular gap:	Other jacking techniques, continous support of annular gap with documentation

4.1.2 Routing and jacking force

Jacking route:	Straight line		
Calculation of the unplanned deviations from the nominal axis (straight track):	Without pilot jacking		
Combination coefficient for pipe's angular deflection:	ψ	0.80	[-]
Specification of thrust force:	No		
Free input of safety coefficient for the longitudinal direction:	No		
Monitored installation:	No		

4.1.3 Pressure transfer ring (PTR)

Kind of thrust transfer:	Without pressure transfer ring

4.1.4 Soil mechanical values

Soil conditions:	Granular soil
Soil group around pipe:	G1
Different soil group above pipe:	No
Bedding angle (granular soil):	2α = 180° (standard case)
Manuel definition inner friction of soil:	No
Manual entering of specific weight of soil:	No

4.1.5 Soil

Manual specification of modulus of deformation of soil:	No
Application of silo theory:	Automatic
Manual specification of K1, δ and c:	No
Compactness of the packing around pipe:	Medium dense to dense
Taking concentration factor λF in account:	No

4.1.6 Loadings

Cover height:	h	1.5	m
Additional surface load:	P_0	0.00	kN/m²
Partial safety factor for outer water pressure:	$\gamma_{F,W}$	1.35	[-]
Groundwater level above pipe invert:	h_{GW}	0.0	m
Inner pressure (operational state):	$P_{I,O}$	0.0	bar
Pipe is filled with liquid during operation:	No		
Free input of safty factor for traffic load:	No		
Traffic load:	Rail Traffic Load LM71, single track		
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Manuell definition reduction ratio for dynamic load:	No		

4.1.7 Calculation options

Buckling proof:	According to A 127
Deformation proof:	According to A 161
Admissible deflection according A161:	Yes
Dynamic proof:	Use standard
Minimum sectional forces according standard:	Yes
Comparison stress minimum sectional forces:	Use design values

4.1.8 Solid/profiled pipes

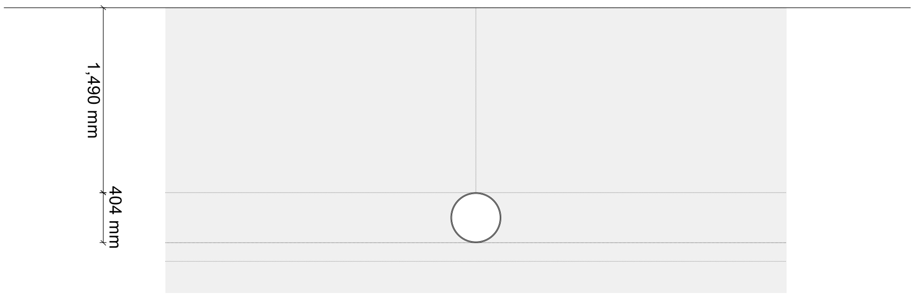
Pipe choice:	Solid wall		
Material class:	Metals		
A type predeformation:	$\delta_{v,TypA}$	1.0	%
Local deformation:	$\delta_{v,lokal}$	0.0	%
Choice of input:	Do and s		
Outer diameter:	d_a	404.0	mm
Wall thickness:	s	10.0	mm
Perforation:	No perforation		
Outer offset:	$\Delta d_{a,min}$	0.0	mm
Internal offset:	$\Delta d_{i,max}$	0.0	mm
Pipe length:	L_R	3.00	m
Manual value for ∆acal:	No		
Pipe end is pre-stressed:	No		
Eccentricity at pipe connection:	vorh e	0.0	mm

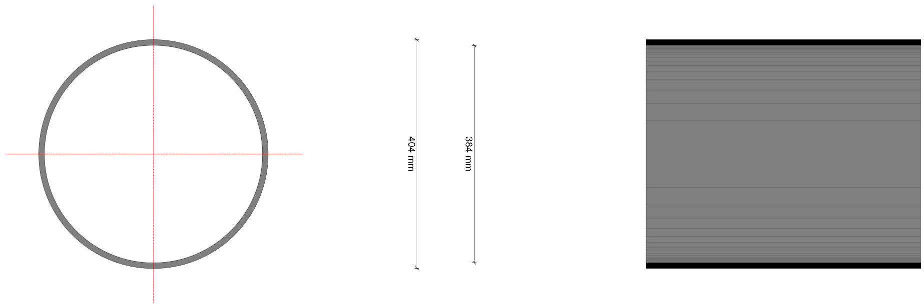
4.1.8.1 Metal

Partial safety coefficient according to standard:	Yes
Choice material:	According to DIN (German standard)
Dyn. Nachweis führen nach:	Regelwerk
Kerbfall nach EC 3-1-9, Bild 7.1:	71
Steel quality DIN:	Steel S235 (EN 10025-2)
Use cross-sectional plastic reserves:	No
Indication of ultimate hoop tensile stress:	Yes
Metal type:	Steel- (ZM), welded pipes

4.1.8.2 System drawing

Rail Traffic Load LM71, single track





4.2 Results

4.2.1 Partial safety coefficients (impacts)

Partial safety factor for non-static loads (traffic loads), radial:	γ_Q	1.35	[-]
Partial safety coefficient for inner pressure (pressure pipes > 0,5 bar):	$\gamma_{F,Pi}$	1.50	[-]
Partial safety factor for static loads, radial:	γ_F	1.35	[-]
Partial safety factor for loads, longitudinal:	$\gamma_{F,ax}$	1.30	[-]

4.2.2 Intermediate results pipe

Inner diameter:	d_i	384.0	mm
Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm
Ratio radius to wall thickness:	r_m/s	19.700	[-]
Curve correction factor, internal:	α_{ki}	1.000	[-]
Curve correction factor, external:	α_{ka}	1.000	[-]
Local predeformation:	δ_{vl}	0.00	%
Predeformation (ovalisation before load):	δ_{vg}	1.00	%
Axially effected profile surface:	A_{ax}	10.00	mm²/mm
Radial cross section:	A_{rad}	10.00	mm²/mm
Distance of inertia:	e	5.00	mm
Moment of inertia:	I	83.33	mm^4/mm
Outer moment of resistance:	W_a	16.67	mm³/mm
Inner moment of resistance:	W_i	16.67	mm³/mm
Surface ratio:	κ_Q	1.2	[-]
Minimum outer diameter:	$d_{a,min}$	404	mm
Maximum inner diameter:	$d_{i,max}$	384	mm
Max. difference of rectangularity concerning the face surface:	$\Delta_{a,cal}$	3.2	mm
Length of the single jacking pipe:	L_R	3.00	m

4.2.2.1 Material properties

Specific gravity:	γ_R	78.5	kN/m³
Poissons ratio:	v	0.30	[-]
Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of Young's modulus in axial direction:	$E_{R,ax}$	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	235.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	235.0	N/mm²
Characteristic value of hoop tensile strength:	σ_{RZ}	235.0	N/mm²
Amplitude for 2·10^6 load cycles:	$2\sigma_{a,2E6}$	71.0	N/mm²
Schwingbreite bei 5·10^6 Lastspielen:	$2\sigma_{a,5E6}$	52.3	N/mm²
Amplitude for 1·10^8 cycles:	$2\sigma_{a,1E8}$	28.8	N/mm²
Characteristic value of axial compressive strength:	σ_{LD}	235.0	N/mm²

4.2.2.2 Safety factors

Local security coifficient for component friction longitudinal to pipe axis:	$\gamma_{M,ax}$	1.35	[-]
Local security coifficient for component friction lateral to pipe axis:	$\gamma_{M,rad}$	1.10	[-]
Local security coifficient for component friction longitudinal on stability:	$\gamma_{M,stab}$	1.85	[-]
Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]

4.2.2.3 Checking of the minimum wallthickness

Outer diameter:	d_a	404.0	mm
Mean radius:	r_m	197.00	mm
Wall thickness:	s	10.00	mm

Calculated minimum wallthickness:	min. t	6.30	mm

The wall thickness is equal to or greater than the minimum wall thickness according to A161 9.3.1 table 19/20!

4.2.3 Intermediate results for the soil

Specific weight of soil:	γ_B	20.0	kN/m³
Buoyant weight of soil:	γ'_B	11.0	kN/m³
Soil group around pipe:	G1		
Angle of inner friction around pipe:	φ'_2	32.5	°
Basis value of modulus of deformation of soil:	E_0	50.00	N/mm²
Coefficient for the compactness of the packing/consistency according A161 table 3/4:	f_1	0.60	[-]
Loosening coefficient caused by jacking according to A161, table 5.:	f_2	0.80	[-]
Angle of inner friction above pipe:	φ'_1	32.5	°
Stress exponent:	z	0.4	[-]
Remarks concerning silo theory:	κ = 1 as there is no dislocation of earth.		
The consideration of concentration factor λF is necessary.:	Yes		
Concentration factor:	λ	1.000	[-]
Base value of earth pressure ratio below crown:	$K_{2,0}$	0.46	[-]
Earth pressure ratio above pipe, construction state:	$K_{2,Bau}$	0.37	[-]
Earth pressure ratio above pipe, operational state:	$K_{2,End}$	0.46	[-]

4.2.4 Operational state

4.2.4.1 Loads Operational state

Impact factor:	Φ_2	1.67	[-]

For pipes which are laid using the jacking method, the greater of the two values a) cover depth (measured from railway sleeper's upper edge to pipe's crown) hü ≥ 1.50 m or b) soil cover (measured from road stone's lower edge to pipe's crown) hB ≥ 2·da, see DWA-A 161 section 6.2.3.3 or Ril 836.4505 (8).

For the execution of crossings under railway systems with smaller cover depths - and in principle with hü < 1.1 m - an internal company permit (Unternehmensinterne Genehmigung, UiG) from DB AG and, if applicable, an approval in individual cases (Zustimmung im Einzelfall, ZiE) from the Federal Railway Authority (Eisenbahn-Bundesamt, EBA) is required.

Commitment of the German railways agency: The impact factor is 1.67 for cover depths hü < 1.50 m.

Impact factor:	red Φ_2	1.67	[-]
Load factor αQi LM71 (DIN EN 1991-2):	$\alpha_{Qi,LM71}$	1.00	[-]
Basic vertical soil stress due to traffic load:	p	55.65	kN/m²
Vertical soil stress at crown height due to traffic load:	p_T	92.94	kN/m²
Vertical soil stresses due to traffic load at springline (without impact factor φ):	p_K	46.27	kN/m²
Earth pressure ratio below crown:	K_2	0.46	[-]
Horizontal soil stress due to traffic load:	$p_{T,h}$	28.58	kN/m²
Vertical soil stress at crown level:	p_{Ev}	29.800	kN/m²
Effective vertical stress at pipe crown level:	q_{Ev}	29.800	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	122.740	kN/m²
Distribution of earth pressure at the pipe is assumed to be cos²- or sin²-shaped.:	No		
Horizontal soil stress at pipe:	q_{Eh}	15.66	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	44.240	kN/m²
Inner gauge pressure:	p_i	0.000	bar
Outer gauge pressure above pipe crown:	$p_{a,Sc}$	0.000	bar
Pipe stiffness:	S_R	2,289	kN/m²
Pipe stiffness:	$\bar{S}_R$	2,289	kN/m²

Scaling reference value:	$\sigma_{B,0}$	100.0	kN/m²
Increase factor due to soil stress:	f_3	1.00	[-]
Modulus of deformation of soil:	E_B	24.00	N/mm²
Earth pressure ratio below crown:	K_2	0.46	[-]
Stiffness of bedding:	S_{Bh}	14.40	N/mm²
System stiffness:	V_{RB}	0.1590	[-]
The pipe soil system is rated flexible:	Yes		

According to DWA-A 161, chapter 6.2.2, the lateral bedding reaction pressure may be applied only if the pipe remains permanently and completely grouted after the jacking is finished.

4.2.4.2 Section forces Operational state

Moments:		crown	springline	invert	
Vertical load due to earth coverage	$M_{pEv,d}$	0.390	-0.390	0.390	kNm/m
Vertical load due to traffic load	$M_{pTv,d}$	1.217	-1.217	1.217	kNm/m
Horizontal load due to traffic	$M_{pTh,d}$	-0.374	0.374	-0.374	kNm/m
Horizontal load due to earth coverage	$M_{pEh,d}$	-0.205	0.205	-0.205	kNm/m
Dead weight	$M_{g,d}$	0.016	-0.018	0.029	kNm/m
Waterfilling upto crown	$M_{w,d}$	0.000	0.000	0.000	kNm/m
Bouyancy (outer water level upto crown)	$M_{a,d}$	0.000	0.000	0.000	kNm/m
Water pressure	$M_{pw,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure due to earth load	$M_{qEh^*,d}$	0.000	0.000	0.000	kNm/m
Bedding reaction pressure	$M_{qh^*,d}$	0.000	0.000	0.000	kNm/m
Sum of moments	ΣM_d	1.044	-1.046	1.057	kNm/m

Normal forces:		crown	springline	invert	
Vertical load due to earth coverage	$N_{pEv,d}$	0.000	-7.925	0.000	kN/m
Vertical load due to traffic	$N_{pTv,d}$	0.000	-24.717	0.000	kN/m
Horizontal load due to traffic	$N_{pTh,d}$	-7.602	0.000	-7.602	kN/m
Horizontal load due to earth coverage	$N_{pEh,d}$	-4.164	0.000	-4.164	kN/m
Dead weight	$N_{g,d}$	0.052	-0.328	-0.298	kN/m
Waterfilling upto crown	$N_{w,d}$	0.000	0.000	0.000	kN/m
Bouyancy (outer groundwater level upto crown)	$N_{a,d}$	0.000	0.000	0.000	kN/m
Water pressure	$N_{pw,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to earth load	$N_{qEh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure due to traffic load	$N_{qTh^*,d}$	0.000	0.000	0.000	kN/m
Bedding reaction pressure	$N_{qh^*,d}$	0.000	0.000	0.000	kN/m
Sum of normal forces	ΣN_d	-11.713	-32.971	-12.064	kN/m

4.2.4.3 Deflection proof Operational state

Deflection coeffizient:	c_{v,qh^*}	0.0640	[-]
Deflection coeffizient:	$c_{v,qv}$	-0.0833	[-]
Coefficient of bedding reaction pressure:	K^*	0.371	[-]
Deflection coefficient:	c^*_v	-0.060	[-]
Vertical soil stress at crown level:	p_{Ev}	29.800	kN/m²
Vertical soil stress due to traffic load:	p_T	92.94	kN/m²
Total vertical soil stresses at pipe crown level:	$q_{Ges,v}$	122.740	kN/m²
Horizontal soil stress at pipe:	q_{Eh}	15.66	kN/m²
Horizontal soil stress due to traffic load:	p_{Th}	28.58	kN/m²
Total horizontal soil stresses at pipe:	$q_{Ges,h}$	44.240	kN/m²
Relative vertical change of diameter:	δ_V	0.20	%
Admissible change of vertical diameter:	zul δ_V	2.00	%
Utilisation factor deflection:	$U_{\delta V}$	10.2	%

The calculated deflection is less than the admissible deflection.

4.2.4.4 Buckling proof Operational state

Local security coifficient for component friction longitudinal on stability regarding the pipe deformation:	$\gamma_{M,stab,red}$	1.45	[-]
Total vertical load, design value:	$q_{v,d}$	165.70	kN/m²

Reduction factor for critical vertical load (acc. A127):	κ_{v2}	0.85	[-]
Critical earth load:	krit $q_{v,d}$	6.871	N/mm²

$$\text{krit}\ q_{v,d} = \kappa_{v2} \cdot \left\{ 3 + \frac{1}{3\ V_{RB}} \right\} \cdot S_R \cdot \frac{1}{\gamma_{M,stab,red}} \qquad (72b)$$

Utilisation factor stability (total vertical load):	U_{qv}	2.4	%
Outer gauge pressure, invert:	$p_{a,So}$	0.000	bar
Maximum external pressure due to water, supporting aids or lubricant, forge pressure:	$p_{a,max}$	0.000	bar
Outer hydrostatic pressure, design value:	$p_{a,d}$	0.00	bar

The buckling proof due to water pressure is not necessary, because there is neither ground water nor depression.

Utilisation factor stability:	$U_{Stab,rad}$	2.4	%

The proof of stability is provided.

4.2.4.5 Stress proof Operational state

Inside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \qquad (54)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} + \alpha_{ki} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \qquad (54)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	60.515	-64.956	60.515	N/mm²
Stress due to other loads	$\sigma_{re,d}$	0.953	-1.111	1.712	N/mm²
Total stress	σ	61.468	-66.067	62.227	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	28.8	---	29.1	%
Utilisation flexural compression:	U_{BD}	---	30.9	---	%

Outside:

$$\sigma_{ST,d} = \frac{\Sigma N_{qv,qh,qh^*,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{qv,qh,qh^*,d}}{W_a} \qquad (55)$$

$$\sigma_{re,d} = \frac{\Sigma N_{sonst,d}}{A_{rad}} - \alpha_{ka} \cdot \frac{\Sigma M_{sonst,d}}{W_a} \qquad (55)$$

		crown	springline	invert	
Stress due to earth and traffic load	$\sigma_{ST,d}$	-62.868	58.427	-62.868	N/mm²
Stress due to other loads	$\sigma_{re,d}$	-0.942	1.046	-1.772	N/mm²
Total stress	σ	-63.810	59.473	-64.640	N/mm²
Relevant flexural tensile strength	$\sigma_{RBZ,res,d}$	213.64	213.64	213.64	N/mm²
Relevant flexural compressive strength	$\sigma_{RBD,res,d}$	213.64	213.64	213.64	N/mm²
Utilisation flexural compression:	U_{BZ}	---	27.8	---	%
Utilisation flexural compression:	U_{BD}	29.9	---	30.3	%

All calculated stresses are smaller than the admissible values.

4.2.4.6 Proof of safety against failure with not predominantly static loading

Gemäß TM 4-2019 der DB Netz AG darf die Schwingbreite für Stahlrohre bei 5·10^6 Lastwechseln nur angesetzt werden, wenn die Überdeckung ≥ 1,5 m ist. Anderenfalls ist der Ermüdungsnachweis für 1·10^8 Zyklen zu führen.

Vertical relevant dynamic pressure in crown level:	dyn p_T	92.94	kN/m²

Horizontal soil stresses due to traffic load for fatigue proof: $p_{Th,E}$ 28.58 kN/m²
Horizontal earth pressure due to traffic load to be considered: dyn p_{Th} 28.6 kN/m²
The supporting effect of the bedding reaction pressure dyn pVh* is not applied, as the pipe-soil-system is not rated as flexible.

		crown	springline	invert	
Normal force due to vertical traffic load	dyn N_{pTv}	0.000	-18.309	0.000	kN/m
Normal force due to horizontal traffic load	dyn N_{pTh}	-5.631	0.000	-5.631	kN/m
Sum of normal forces due to traffic load	dyn ΣN	-5.631	-18.309	-5.631	kN/m
Moment due to vertical traffic load	dyn M_{pTv}	0.902	-0.902	0.902	kNm/m
Moment due to horizontal traffic load	dyn M_{pTh}	-0.277	0.277	-0.277	kNm/m
Sum of moments due to traffic load	dyn ΣM	0.624	-0.624	0.624	kNm/m
Sum of moments due to static loads	ΣM_g	0.149	-0.151	0.159	kNm/m
Sum of normal forces due to static loads	ΣN_g	-3.046	-6.114	-3.305	kN/m

Amplitude with 1·10^8 tests: $2\sigma_{a,1E8}$ 28.755 N/mm²

Inside					
Curve correction factor, internal:			α_{ki}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	36.902	-39.296	36.902	N/mm²
Utilisation factor dynamic stress component	dyn U	141.2	---	141.2	%
outside					
Curve correction factor, external:			α_{ka}	1.000	[-]
Dynamic stress component	dyn σ_{pT}	-38.028	35.634	-38.028	N/mm²
Utilisation factor dynamic stress component	dyn U	---	136.3	---	%

The proof of safety against failure with not predominantly static loading could not be provided.

CAUTION - not all necessary proofs have passed!

5 Statics according to ATV-DVWK-A 127, 3rd edition: Grabenverlegung Stahlrohr OHNE TM

Caption of this part of the calculation:	Grabenverlegung Stahlrohr OHNE TM

Kind of calculation:	Solid wall
Add sketch to print:	Yes

5.1 Input

5.1.1 Safety factors

Safety class:	A (normal case)		
Safety stability according to table 13:	Without predeformation (2.5 / 2.0)		
Allowable deflection:	6% (standard)		
Treatment of internal pressure:	In accordance with Footnote 39 in ATV-DVWK-A 127		
Lower safety factors for flexural compression:	No (ATV-DVWK-A 127)		
Proof for not predominantly static loading:	According to standard		
Consideration of dyn pvh*:	According to standard		
Consideration of Type A 'predeformation' in the deformation proof:	Yes		

5.1.2 Soil

Soil group backfill:	G1		
Calculation E1:	Table 8 (A127)		
Soil group pipe zone:	G1		
Calculation E20:	Table 8 (A127)		
Soil group native soil:	G1		
Calculation E3:	Compression ratio		
Compression ratio E3:	$D_{Pr,E3}$	99.0	%
E4 = 10 · E1:	Yes		
Application of silo theory:	Automatic		

5.1.3 Load

Cover depth:	h	3.50	m
Minimum groundwater level above pipe bed:	$h_{W,min}$	0.00	m
Maximum groundwater level above pipe bed:	$h_{W,max}$	0.00	m
Soil density:	γ	20.0	kN/m³
Additional surface load:	p_0	0.0	kN/m²
Inner pressure, long term:	$P_{I,L}$	0.00	bar
Water fill (e.g. damming channel):	Yes		
Density of medium:	γ_F	10.0	kN/m³
Input special-purpose vehicle:	No		
Traffic load:	Railway, single-track, LM 71		
Including horizontal loads due to traffic in the fatigue proof:	$\alpha_{qhT,dyn}$	0.00	%

5.1.4 Installation

Installation:	Trench		
Trench width at pipe crown level:	b	1.80	m
Check minimum trench width:	No		
Automatic consideration of bedding layer:	Yes		
Slope angle:	ß	90	°
Cover condition:	A1		

Installation condition:	B1		
Type of bedding:	Loose		
Bedding angle:	120°		
Calculate bedding automatically:	Yes		
Set lower height base:	No		
Total height of base:	h_s	0.00	m

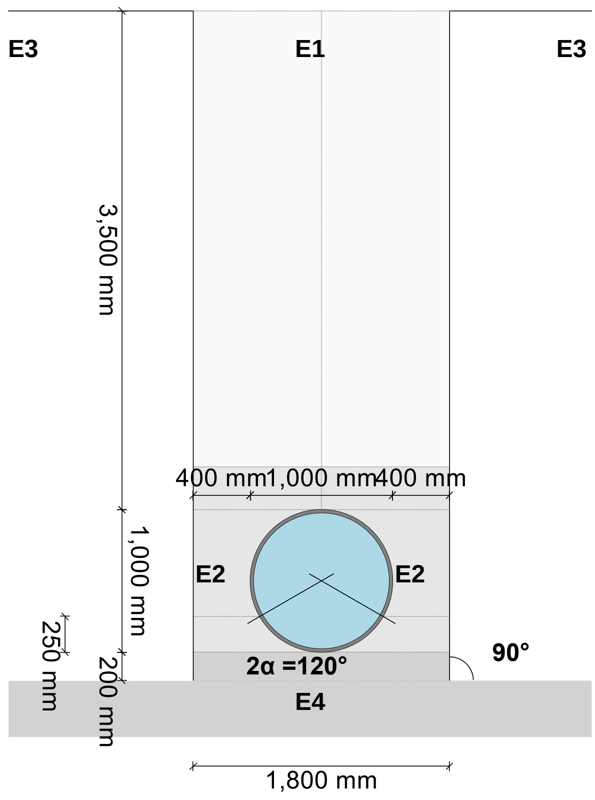
5.1.5 Solid/profiled pipes

Pipe choice:	Solid wall		
Material class:	Metals		
A type predeformation:	$\delta_{v,TypA}$	1.0	%
Local deformation:	$\delta_{v,lokal}$	0.0	%
Choice of input:	Do and s		
Outer diameter:	d_a	1,000.0	mm
Wall thickness:	s	25.0	mm
Perforation:	No perforation		

5.1.5.1 Metal

Choice material:	According to DIN (German standard)
Steel quality DIN:	Steel S235 (EN 10025-2)
Use cross-sectional plastic reserves:	No
Indication of ultimate hoop tensile stress:	Yes

Traffic load: Railway, single-track, LM 71



5.2 Results

5.2.1 Intermediate results pipe

Inner diameter:	d_i	950.0	mm
Outer diameter:	d_a	1,000.0	mm
Mean radius:	r_m	487.50	mm
Wall thickness:	s	25.00	mm
Ratio radius to wall thickness:	r_m/s	19.500	[-]
Curve correction factor, internal:	α_{ki}	1.017	[-]
Curve correction factor, external:	α_{ka}	0.983	[-]
Local predeformation:	δ_{vl}	0.00	%
Predeformation (ovalisation before load):	δ_{vg}	1.00	%
Radial cross section:	A_{rad}	25.00	mm²/mm
Distance of inertia:	e	12.50	mm
Moment of inertia:	I	1,302.08	mm^4/mm
Outer moment of resistance:	W_a	104.17	mm³/mm
Inner moment of resistance:	W_i	104.17	mm³/mm
Surface ratio:	κ_Q	1.2	[-]

5.2.1.1 Material properties

Specific gravity:	γ_R	78.5	kN/m³
Poissons ratio:	ν	0.30	[-]
Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	225.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	225.0	N/mm²
Characteristic value of hoop tensile strength:	σ_{RZ}	225.0	N/mm²
Amplitude for 2·10^6 load cycles:	$2\sigma_{a,2E6}$	140.0	N/mm²
Schwingbreite bei 5·10^6 Lastspielen:	$2\sigma_{a,5E6}$	103.2	N/mm²
Amplitude for 1·10^8 cycles:	$2\sigma_{a,1E8}$	56.7	N/mm²

5.2.1.2 Safety factors

Required safety coifficient, bending tensile stress:	erf γ_{RBZ}	1.50	[-]
Required safety coifficient, bending compressive stress:	erf γ_{RBD}	1.50	[-]
Required safety coifficient, instability (buckling):	erf γ_{stab}	2.50	[-]

5.2.1.3 Minimum trench width according to DIN EN 1610:2015-12

The minimum trench width according to DIN EN 1610 / DWA-A 139 is not checked.

5.2.2 Intermediate results for load case

5.2.2.1 Silo Theory

Soil load coefficient κ for trench load (Silo Theory):	κ	0.677	[-]
Soil load coefficient κ0 for surface load (Silo Theory):	κ_0	0.432	[-]

5.2.2.2 Load

Maximum groundwater level above pipe crown:	$h_{W,Scheitel}$	0.00	m
Vertical soil stress from soil load:	p_{Erd}	47.38	kN/m²
Vertical soil stress from soil and surface load:	p_E	47.38	kN/m²
Stress due to traffic load:	p_V	43.07	kN/m²
Included impact factor:	ϕ	1.42	[-]
Stresses due to traffic load (dynamic proof):	p_T	43.07	kN/m²

5.2.2.3 Soil deformation moduli EB

Backfill elastic modulus under load:	$E_{1,\sigma}$	16.00	N/mm²

$$E_{3,\sigma} = \frac{40}{1} \cdot e^{-0.188(100 - D_{Pr})} \quad 3.01$$

Native soil elastic modulus:	$E_{3,\sigma}$	33.14	N/mm²
Bedding elastic modulus under load:	$E_{20,\sigma}$	16.00	N/mm²
Reduction factor for creep:	f_1	1.000	[-]
Reduction factor E20 (groundwater):	f_2	1.000	[-]
Reduction factor E20 (Diagram 5):	α_{B0}	0.667	[-]
Reduction factor E20 (narrow trench):	α_B	0.756	[-]
Bedding elastic modulus (reduced):	$E_{2,\sigma}$	12.09	N/mm²
Elastic modulus of soil under pipe:	$E_{4,\sigma}$	160.00	N/mm²

5.2.2.4 Soil stiffness values

Auxiliary value for horizontal bedding stiffness:	Δ_f	0.662	[-]
Correction factor for horizontal bedding stiffness:	ζ	1.621	[-]
Horizontal bedding stiffness:	S_{Bh}	11.755	N/mm²
Vertical bedding stiffness:	S_{Bv}	12.089	N/mm²

5.2.2.5 Bedding angle, effective relative projection and friction angle

Bedding angle, effective relative projection and friction angle:	2α	120	°
Height bedding from bedding angle to lower pipe ledge:	t_r	0.250	m
Calculated relative projection:	a	1.00	[-]
Effective relative projection:	a'	1.324	[-]
Internal friction angle:	φ'	35.000	°
Wall friction angle:	δ	23.333	°

5.2.2.6 Characteristic values of pipe material and ring stiffness

Characteristic value of Young's modulus in circumferential direction:	E_R	210,000.0	N/mm²
Characteristic value of radial flexural stress:	σ_{RBZ}	225.0	N/mm²
Characteristic value of radial bending compressive strength:	σ_{RBD}	225.0	N/mm²
Pipe stiffness:	S_R	2,360	kN/m²

5.2.2.7 Stiffness ratio

System stiffness:	$V_{RB,w}$	0.2008	[-]
Stiffness ratio:	V_S	2.8749	[-]
Coefficient for bedding reaction pressure:	c_v^*	-0.068	[-]

5.2.2.8 Coefficients

Ground pressure ratio (bedding):	K_2	0.400	[-]
Coefficient for bedding reaction pressure:	K*	0.334	[-]
Resulting deformation coefficient:	$c'_{h,qv}$	0.0891	[-]
Resulting deformation coefficient:	c'_{h,qh^*}	-0.0658	[-]
Coefficient for bedding reaction pressure:	c_v^*	-0.068	[-]

5.2.2.9 Concentration factors λR and λB

Maximum concentration factor:	max λ	1.699	[-]
Coefficient for maximum concentration factor:	K'	0.932	[-]
Concentration factor above pipe, initial value:	λ_R	1.382	[-]
Concentration factor above pipe, under trench effect:	λ_{RG}	1.102	[-]
Concentration factor above pipe, upper limit:	λ_{fo}	3.475	[-]
Concentration factor above pipe, lower limit:	λ_{fu}	0.373	[-]
Concentration factor above pipe, final value:	λ_{RG}	1.102	[-]
Soil concentration factor:	λ_B	0.873	[-]

5.2.2.10 Pressure distribution at pipe circumference

Total vertical load:	q_v	95.28	kN/m²
Lateral pressure:	q_h	20.54	kN/m²
Bedding reaction pressure (soil load):	q^*_h	25.43	kN/m²

Bedding reaction pressure (water filling):	q^*_{hw}	1.30	kN/m²

5.2.3 Section forces , long term

		crown	springline	invert	
Moment due to total vertical load	M_{qv}	5.910	-6.001	6.227	kNm/m
Moment due to lateral pressure	M_{qh}	-1.220	1.220	-1.220	kNm/m
Moment due to horizontal bedding reaction pressure	M^*_{qh}	-1.094	1.257	-1.094	kNm/m
Moment due to horizontal bedding reaction pressure (water filling)	M^*_{qw}	-0.056	0.064	-0.056	kNm/m
Moment due to dead weight	M_g	0.178	-0.205	0.243	kNm/m
Moment due to water filling	M_w	0.220	-0.255	0.301	kNm/m
Moment due to water pressure/internal pressure	M_{pw}	0.000	0.000	0.000	kNm/m
Total moments	ΣM	3.938	-3.919	4.401	kNm/m

		crown	springline	invert	
Normal force due to total vertical load	N_{qv}	1.254	-46.451	-1.254	kN/m
Normal force due to lateral pressure	N_{qh}	-10.013	0.000	-10.013	kN/m
Normal force due to horizontal bedding reaction pressure	N^*_{qh}	-7.153	0.000	-7.153	kN/m
Normal force due to horizontal bedding reaction pressure (water filling)	N^*_{qw}	-0.365	0.000	-0.365	kN/m
Normal force due to dead weight	N_g	0.239	-1.503	-0.239	kN/m
Normal force due to water filling	N_w	1.485	0.511	3.268	kN/m
Normal force due to water pressure/internal pressure	N_{pw}	0.000	0.000	0.000	kN/m
Total normal forces	ΣN	-14.553	-47.443	-15.757	kN/m

Included impact factor:	ϕ	1.42	[-]
Stresses due to traffic load (dynamic proof):	p_T	43.07	kN/m²
Reduction factor αV according table 14 for traffic load:	α_V	1.00	[-]
Reduced vertical soil stress due to traffic load:	dyn p_V	43.073	kN/m²

The supporting effect of the bedding reaction pressure dyn pVh* is not applied because of a compression ratio < 97% (chosen manually or due to ATV-DVWK-A 127 table 8; here for B4 ≥ 97% only).

		crown	springline	invert	
	m_{qv}	0.261	-0.265	0.275	[-]
Moment due to traffic loads	dyn M_{qv}	2.672	-2.713	2.815	kNm/m
Sum of moments due to traffic loads	$M_{QK,dyn}$	2.672	-2.713	2.815	kNm/m

	n_{pv}	0.027	-1.000	-0.027	[-]
Normal force due to traffic loads	dyn N_{qv}	0.567	-20.998	-0.567	kN/m
Sum of normal forces due to traffic loads	$N_{QK,dyn}$	0.567	-20.998	-0.567	kN/m

5.2.4 Long term load case

5.2.4.1 Stress proof

$$\sigma_{R,res} = \frac{|\sigma_{qv,qh,qh^*}| \cdot \bar{\sigma}_R + |\sigma_{sonst}| \cdot \sigma_{R,L}}{|\sigma_{qv,qh,qh^*}| + |\sigma_{sonst}|} \quad (9.01c)$$

Required safety coifficient, bending tensile stress:	erf γ_{RBZ}	1.50	[-]
Required safety coifficient, bending compressive stress:	erf γ_{RBD}	1.50	[-]

Flexural tensile strength to be considered	$\sigma_{RBZ,res}$	225.00	225.00	225.00	N/mm²

Flexural compressive strength to be considered	$\sigma_{RBD,res}$	225.00	225.00	225.00	N/mm²

Inside

Curve correction factor, internal:			α_{ki}	1.017	[-]
		crown	springline	invert	
Stress due to soil and traffic loads	σ_{qv,qh,qh^*}	34.475	-36.261	37.471	N/mm²
Stress due to other loads	σ_{sonst}	3.394	-3.906	4.871	N/mm²
Total stress	σ	37.869	-40.167	42.341	N/mm²
Safety coefficient flexural tension:	γ_{BZ}	5.942	---	5.314	[-]
Safety coefficient flexural compression:	γ_{BD}	---	5.602	---	[-]

outside

Curve correction factor, external:			α_{ka}	0.983	[-]
		crown	springline	invert	
Stress due to soil and traffic loads	σ_{qv,qh,qh^*}	-34.568	31.389	-37.660	N/mm²
Stress due to other loads	σ_{sonst}	-3.173	3.696	-4.497	N/mm²
Total stress	σ	-37.741	35.085	-42.157	N/mm²
Safety coefficient flexural tension:	γ_{BZ}	---	6.413	---	[-]
Safety coefficient flexural compression:	γ_{BD}	5.962	---	5.337	[-]

All calculated safety coefficients of the stress proof are sufficient.

5.2.4.2 Deformation proof

Calculation mode:	linear		
Ratio:	$I/(A \cdot rm^2)$	0.00022	[-]
Ratio 'I/(A·rm²)·κ~Q':	$I/(A \cdot rm^2) \cdot \kappa_Q$	0.00026	[-]

		q_v	q_h	q_h^*	
Deflection coefficient for bending moments	c_v	-0.0893	0.0833	0.0640	[-]

The modifictaion of the coefficients for the moments according to ATV-DVWK-A 127 table 10a is not used, because formula 6.19a and formula 6.19b < 0.001

Resulting deformation coefficient	c'_v	-0.0893	0.0833	0.0640	[-]
Resulting deformation coefficient	$c'_{h,qv}$	0.0891	-0.0833	-0.0658	[-]

Vertical diameter change:	Δd_v	2.14	mm
Horizontal diameter change:	Δd_h	2.11	mm
Relative vertical deformation (due to loads, elastic, Type B):	$\delta_{v,B}$	0.22	%
Local 'predeformation' (e. g. due to manufacturing, plastic, Type A):	$\delta_{v,A}$	1.00	%
Total vertical deformation (Type A + Type B):	$\delta_{v,Ges}$	1.22	%
Allowable deflection:	zul δ_v	6.00	%

The deflection determined is less than the allowable deflection.

5.2.4.3 Stabilitätsnachweis, linear:

Total vertical load:	q_v	95.28	kN/m²
Abminderungsfaktor Beullast bei Erd-/Verkehrslasten:	κ_{v2}	0.85	[-]
Kritische vertikale Gesamtlast:	krit q_v	9,349.0	kN/m²

Der Beulnachweis für Wasserdruck entfällt, da weder Grundwasser ansteht noch Unterdruck vorliegt.

Sicherheitsbeiwert Stabilität:	γ	98.12	[-]
Required safety coifficient, instability (buckling):	erf γ_{stab}	2.50	[-]

Der Stabilitätsnachweis ist erbracht.

5.2.4.4 Stabilty proof radial, linear

Earth and traffic loads

Pipe stiffness:	$\bar{S}_R$	2,360	kN/m²
Horizontal bedding stiffness:	S_{Bh}	11.755	N/mm²
System stiffness:	$V_{RB,w}$	0.2008	[-]
Reduction factor buckling load for earth/traffic loads:	κ_{v2}	0.85	[-]
Internal friction angle:	φ'	35.000	°
Critical vertical total load:	krit q_v	9,349.0	kN/m²
Total vertical load:	q_v	95.28	kN/m²
Safety stability, radial:	$\gamma_{Stab,rad}$	98.12	[-]
Required safety coifficient, instability (buckling):	erf γ_{stab}	2.50	[-]

The buckling proof is fulfilled.

5.2.4.5 stability proof, nonlinear

The nonlinear stability proof is not applicable because of VRB > 1.0 (rigid pipe) or relative vertical deformation < 6%.

5.2.4.6 Proof of safety against failure with not predominantly static loading

Amplitude with 1·10^8 tests:	$2\sigma_{a,1E8}$	56.700	N/mm²
Included impact factor:	ϕ	1.42	[-]
Stresses due to traffic load (dynamic proof):	p_T	43.07	kN/m²
Reduction factor αV according table 14 for traffic load:	α_V	1.00	[-]
Reduced vertical soil stress due to traffic load:	dyn p_V	43.073	kN/m²

The supporting effect of the bedding reaction pressure dyn pVh* is not applied because of a compression ratio < 97% (chosen manually or due to ATV-DVWK-A 127 table 8; here for B4 ≥ 97% only).

		crown	springline	invert	
	m_{qv}	0.261	-0.265	0.275	[-]
Moment due to traffic loads	dyn M_{qv}	2.672	-2.713	2.815	kNm/m
Sum of moments due to traffic loads	$M_{QK,dyn}$	2.672	-2.713	2.815	kNm/m
	n_{pv}	0.027	-1.000	-0.027	[-]
Normal force due to traffic loads	dyn N_{qv}	0.567	-20.998	-0.567	kN/m
Sum of normal forces due to traffic loads	$N_{QK,dyn}$	0.567	-20.998	-0.567	kN/m
Inside					
Dynamic stress portion external	dyn σ_{pV}	26.110	-27.327	27.464	N/mm²
Safety coefficient external:	dyn γ	2.172	---	2.065	[-]
Required safety coefficient:			erf γ	2.000	[-]
outside					
Dynamic stress portion external	dyn σ_{pV}	-25.188	24.757	-26.585	N/mm²
Safety coefficient external:	dyn γ	---	2.290	---	[-]
Required safety coefficient:			erf γ	2.000	[-]

The determined safety coefficients are sufficient.

All necessary proofs are ok.