# RIB-Programm DWA-A161 18.0 Analysis of JACKING PIPES Page 1

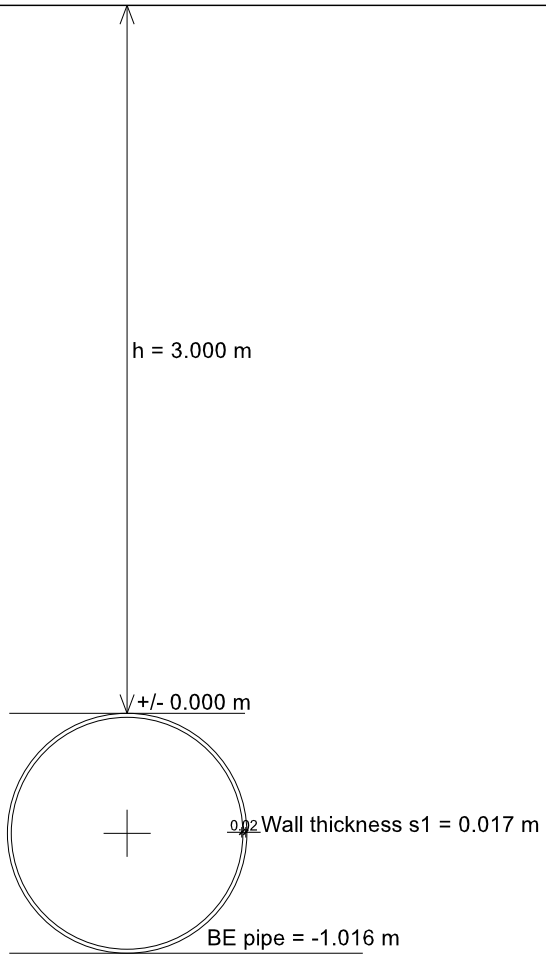
Stahlvortriebsrohre DN 1000 LM101

## RIB DURO: Construction state

7.0 Steel pipe - with or without cement mortar

### Soil class:

G1: non-cohesive soils
Friction angle φ = 25.00 °
Unit weight $\gamma_B$ = 1.00 kN/m$^3$
Buoyant unit weight $\gamma_B'$ = 11.00 kN/m$^3$
Traffic class: Load model LM1+LM3



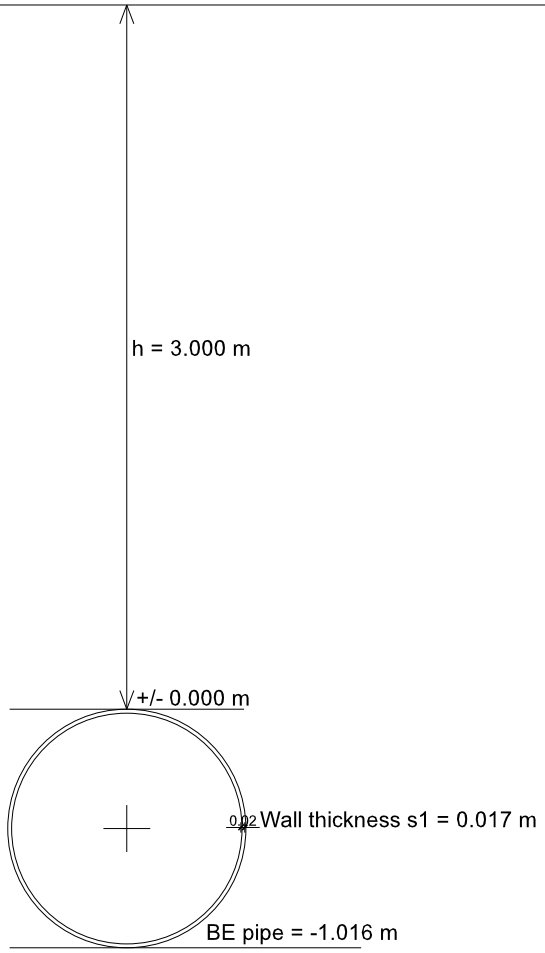
## RIB DURO: Operating state

7.0 Steel pipe - with or without cement mortar

### Soil class:

G1: non-cohesive soils
Friction angle φ = 25.00 °
Unit weight $\gamma_B$ = 1.00 kN/m$^3$
Buoyant unit weight $\gamma_B'$ = 11.00 kN/m$^3$

Traffic class: Load model LM1+LM3



```
Input file: _DURO.DUR
Datum/Date: 19.10.2018
------------------------------------------------------------------------
Echo print of input data:
------------------------------------------------------------------------
KOPF Stahlvortriebsrohre DN 1000 LM101
SEIT 1 1 69 0 0 1 0 0 1
ROHR 7.000 982.800 16.600 16.600 16.600 0.000
W*** Durohr: For pipe code 7.0 the sel. cement mortar lining thickness is =
0.0
TSIB 1.350 1.350 1.500 1.150 0.850 1.350 1.000 1.000 1.150 1.300
TSBR 1.500 1.500 0.900
SPE1 78.5 210000. 210000. 320. 140. 0. 0. - -
SPE2 - - 1.330 2.500
BODN 1 1.00 11.00 - - - 0.40 1 0 - - - -
BNK2 - - 0.10 - 0 -
GWAS - - - -
LAST 3.000 0.000 101 - - - 0.000 0.000 - 1.000
BELA 3.000 0.000 101 - - - 10.000 0.000 - 1.000
PRES 6000.000 0.000 0.000 320.000 360.000 0.000 0 50.000
TRAS 1 0 0 1 800. 3
DROR 10. 150000. 360. 1.35 1.15 0. 235. -
DUER 0 30. - - - - - 1 1 1
ABWI - - -
ENDE
```

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Check of minimum wall thickness acc. to DWA-A161: Tab.19 and 20

| | | |
|---|---|---|
| Outer diameter | Da = | 1016.0 mm |
| Mean radius | Rm = | 499.7 mm |
| Min. wall thickness | t.min = | 10.1 mm |
| Exis. wall thickness | t.exis = | 16.6 mm |

# STRUCTURAL ANALYSIS OF JACKING PIPES

Acc. to DVGW Merkblatt GW312 resp. DWA Arbeitsblatt A161, March 2014

Structural design calculation of jacking pipes of type
Steel pipes acc. to DIN 1629/1626

## Record of input data:

Dimensions and material data:

| | | |
|---|---|---|
| Nominal diameter | DN 1000 | |
| Outer diameter | Da = | 1016.0 mm |
| Inner diameter | Di = | 982.8 mm |
| Wall thickness | t = | 16.6 mm |

Rebated depth in range of pipe connection:

| | | |
|---|---|---|
| ext. delta.t = | 0 | mm |
| int. delta.t = | 0 | mm |

**Material properties:**

| | | |
|---|---|---|
| Unit weight of pipe material | UnitWeight.R = | 78.500 kN/m3 |
| Youngs modulus of the pipe | E.R = | 210000 N/mm2 |
| Cal. value of bending stress | sigma.R = | 320.0 N/mm2 |

**Partial safety factors (PSF):**

| | | |
|---|---|---|
| Design value for permanent actions | gamma.G | = 1.35 |
| Design value for transient actions | gamma.Q | = 1.35 |
| PS factor for concrete | gamma.c | = 1.50 |
| PS factor for reinforcement steel | gamma.s | = 1.15 |
| Factor for concrete strength decrease | alpha.D | = 0.85 |
| Bearing capacity coefficient | gamma.R | = 1.35 |
| Used for fatigue analysis are: | | |
| PS factor for actions | gamma.F,fat | = 1.00 |
| PS factor for model insecurities | gamma.Ed,fat | = 1.00 |
| PS factor for reinforcement steel | gamma.s,fat | = 1.15 |

Stahlvortriebsrohre DN 1000 LM101

**Pipe joints:**

The planned jacking alignment is straight. The jacking is done under under elaborate surveying and controlling in a way, that the construction company can guarantee a compressive stress transfer in the compressed zone with a gaping dimension of 0.28 from straight jacking.
The minimum design stress resultants are increased by 0.0 %
for the present calculation of jacking pipes.

## MINIMUM DESIGN (Constraining forces in the construction state)

```
Sum M.Springing =  -45.0 * Rm2
Sum M.Crown     =   45.0 * Rm2
Sum M.Base      =   45.0 * Rm2
                                1.0 > z/da >= 0.28
Sum N.Springing = -270.0 * Rm
Sum N.Crown     = -135.0 * Rm
Sum N.Base      = -135.0 * Rm
```

Stahlvortriebsrohre DN 1000 LM101

| Section | | Springline | Pipe crown | Pipe base |
|---|---|---|---|---|
| **Cross-section values:** | | | | |
| Area | (cm2/m) | 166.00 | 166.00 | 166.00 |
| Resistance moment | (cm3/m) | 45.93 | 45.93 | 45.93 |
| Correction factor alpha.KI | | 1.01 | 1.01 | 1.01 |
| Correction factor alpha.KA | | 0.99 | 0.99 | 0.99 |

**Stress resultants**

| Moments | (kNm/m): | | | |
|---|---|---|---|---|
| Sum M.q = (total load) | | -11.24 | 11.24 | 11.24 |
| **Normal forces** | **(kN/m):** | | | |
| Sum N.q = (total load) | | -134.92 | -67.46 | -67.46 |

Stress verification (design) according to section 9.4.3 (N/mm2)

| | | | |
|---|---|---|---|
| Sigma.M inside = M*alfa.I/W | -244.7 | 244.7 | 244.7 |
| Sigma.M outsde = M*alfa.A/W | 244.7 | -244.7 | -244.7 |
| Sigma.N = N/A | -8.1 | -4.1 | -4.1 |
| exis.Sigma inside from N+M | -252.8 | 240.6 | 240.6 |
| exis.Sigma outside from N+M | 236.5 | -248.7 | -248.7 |
| adm. Beta.BZR | 320.0 | 320.0 | 320.0 |
| adm. Beta.D | 360.0 | 360.0 | 360.0 |
| Safety coefficients: | | | |
| Gamma provided | 1.23 | 1.21 | 1.21 |
| Gamma required | 1.00 | 1.00 | 1.00 |

Placing:
The assembly of the jacking pipes is done using the underground pipe jacking method. The jacking pipes are assembled behind a cutting tool in the jacking shaft and pushed into place by jacking force.
The jacking forces are transferred directly within the pipe joints.
The surveying and exact control as well as accurate soil excavation are requirements to get reliable results.
For the placing must be considered:
DVGW Merkblatt W304 resp. ATV Arbeitsblatt A125: Pipe jacking and related methods

OBSERVE ASSEMBLY SPECIFICATIONS:
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Prerequisite for the usefulness of the following jacking pipe design results are
- A permanent bentonite lubrication during the jacking works
- as well as a grouting of the annulus area between jacking pipe and soil after finishing the jacking.

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Soil and jacking data in the construction state

**SOIL DATA:**

Decisive soil type according to GW312/A161-Tab.1: soil group G1

The soil groups signify
Group 1: non-cohesive sands and gravel
Group 2: slightly cohesive sands and gravel
Group 3: cohesive mixed soils and silt
Group 4: cohesive soils

Pipe jacking in loose sediments
with support angle 2alpha = 180 Deg.
Unit weight above water Gamma-numerical = 1.00 kN/m3
Unit weight below water Gamma-buoyancy = 11.00 kN/m3

EarthPressure ratio above pipe crown K1 = 0.400
below pipe crown K2 in constr. state = 0.400
Angle of internal friction Phi' = 32.50 Deg.
Friction angle in the shear joint Del' = 16.25 Deg.
Packing density in constr. state D = 0.40
1. Factor for deform. modulus f1 = 0.40
2. Factor for deform. modulus in CS f2 = 1.00
Deformation module in constr. state E.B = 20.00 N/mm2

Reduction factor for arching in the constr. state Kappa = 0.825
Reduction factor for arching
under loading in the construction state Kappa.0 = 0.672

## CALCULATION OF THE CONSTRUCTION STATE (CS)

Load assumptions:
- Soil cover height h = 3.00 m
- Traffic load type = LM1 Load model
- No ground water
- Pipe empty

### LOAD DATA

Soil loads without buoyancy

| | | | |
|---|---|---|---|
| Vertical earth load | q0 = | 3.1 | kN/m2 |
| Surcharge | p0 = | 0.0 | kN/m2 |
| Horizon. earth load | eh = | 1.4 | kN/m2 |

Traffic loads

| | | | |
|---|---|---|---|
| Traffic load | p = | 18.63 | kN/m2 |
| Impact coefficientwir. | phi = | 1.20 | |
| Impact coefficient | phi0 = | 1.20 | |
| statically acting | pV = | 22.4 | kN/m2 |
| statically acting | pH = | 2.6 | kN/m2 |

| | | | |
|---|---|---|---|
| Maximum total loading | qv = | 25.5 | kN/m2 |
| | qh = | 4.1 | kN/m2 |

Stahlvortriebsrohre DN 1000 LM101

| Section | | Springline | Pipe crown | Pipe base |
|---|---|---|---|---|
| **Cross-section values:** | | | | |
| Area | (cm2/m) | 166.00 | 166.00 | 166.00 |
| Resistance moment | (cm3/m) | 45.93 | 45.93 | 45.93 |
| Correction factor alpha.KI | | 1.01 | 1.01 | 1.01 |
| Correction factor alpha.KA | | 0.99 | 0.99 | 0.99 |

**Stress resultants acc. to section 7 and 8**

| | | | |
|---|---|---|---|
| Moments (kNm/m): | | | |
| M.G = (Dead load ) | -0.142 | 0.125 | 0.230 |
| M.w = (WaterCont./Groundw.) | 0.000 | 0.000 | 0.000 |
| M.ev = (Soil load vertical ) | -0.129 | 0.129 | 0.129 |
| M.eh = (SoilLoad horizontal) | 0.060 | -0.060 | -0.060 |
| M.eh*= (Foundation reaction) | 0.000 | 0.000 | 0.000 |
| M.pV = (Live load vertical ) | -1.396 | 1.396 | 1.396 |
| M.pH = (LiveLoad horizontal) | 0.163 | -0.163 | -0.163 |
| M.ph*= (Traffic found.react) | 0.000 | 0.000 | 0.000 |
| M.auf= (Buoyancy ) | 0.000 | 0.000 | 0.000 |
| Sum M.q = (total load) | -1.443 | 1.426 | 1.531 |
| M.Gk (Sum permanent load ) | -0.211 | 0.194 | 0.299 |
| M.Qk (Sum variable load ) | -1.232 | 1.232 | 1.232 |
| M.Gd=gamma.G*M.Gk=1.35*M.Gk | -0.285 | 0.262 | 0.403 |
| M.Qd=gamma.Q*M.Qk=1.35*M.Qk | -1.664 | 1.664 | 1.664 |
| M.Ed = M.Gd + M.Qd | -1.949 | 1.925 | 2.067 |
| Normal forces (kN/m): | | | |
| N.g = (Dead load ) | -1.023 | 0.163 | -0.930 |
| N.w = (WaterCont./Groundw.) | 0.000 | 0.000 | 0.000 |
| N.ev = (Soil load vertical ) | -1.031 | -0.515 | -0.515 |
| N.eh = (SoilLoad horizontal) | -0.240 | -0.480 | -0.480 |
| N.eh*= (Foundation reaction) | 0.000 | 0.000 | 0.000 |
| N.pV = (Live load vertical ) | -11.172 | 0.000 | 0.000 |
| N.pH = (LiveLoad horizontal) | 0.000 | -1.309 | -1.309 |
| N.ph*= (Traffic found.react) | 0.000 | 0.000 | 0.000 |
| N.auf= (Buoyancy ) | 0.000 | 0.000 | 0.000 |
| Sum N.q = (total load) | -13.467 | -2.141 | -3.234 |
| N.Gk (Sum permanent load ) | -2.294 | -0.832 | -1.925 |
| N.Qk (Sum variable load ) | -11.172 | -1.309 | -1.309 |
| N.Gd=gamma.G*N.Gk=1.35*N.Gk | -3.097 | -1.124 | -2.599 |
| N.Qd=gamma.Q*N.Qk=1.35*N.Qk | -15.083 | -1.767 | -1.767 |
| N.Ed = N.Gd + N.Qd | -18.180 | -2.891 | -4.366 |

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| Stress verification (characteristic) according to section 9.4.3 (N/mm2) | | | |
|---|---|---|---|
| Sigma.M inside = M*alfa.I/W | -31.4 | 31.1 | 33.3 |
| Sigma.M outsde = M*alfa.A/W | 31.4 | -31.1 | -33.3 |
| Sigma.N = N/A | -0.8 | -0.1 | -0.2 |
| exis.Sigma inside from N+M! | -32.2 | 30.9 | 33.1 |
| exis.Sigma outside from N+M! | 30.6 | -31.2 | -33.5 |

| Stress verification (design) according to section 9.4.3 (N/mm2) | | | |
|---|---|---|---|
| Sigma.M inside = M*alfa.I/W | -42.4 | 41.9 | 45.0 |
| Sigma.M outsde = M*alfa.A/W | 42.4 | -41.9 | -45.0 |
| Sigma.N = N/A | -1.1 | -0.2 | -0.3 |
| prov. Sigma inside from N+M! | -43.5 | 41.7 | 44.7 |
| prov. Sigma outsde from N+M! | 41.3 | -42.1 | -45.3 |
| adm. Beta.BZR | 320.0 | 320.0 | 320.0 |
| adm. Beta.D | 360.0 | 360.0 | 360.0 |
| Safety coefficients: | | | |
| Gamma provided | 7.04 | 6.97 | 6.50 |
| Gamma required | 1.00 | 1.00 | 1.00 |

Analysis of the effective stress in the construction state

Raw data:
Longitudinal compressive strength beta.LD = 320.0 N/mm2
Longitudinal tensile strength sigm.z = 360.0 N/mm2
Flexural tensile strength sigm.R = 320.0 N/mm2
Part. safety factor for axial member resis. gamM.axl = 1.35
P.s.f. for failure due to cross fracture gamma.A = 1.10
max. longit. compressive stress (Design) sigm.max.L.d = 172.15 N/mm2
max. corr. circumferential stress (Design) sigm.max.R.d = 44.74 N/mm2

Verification:
Equivalent stress sigm.VGE.d = 154.71 N/mm2
max. adm. equivalent stress beta.LD/gamM.axl= 237.04 N/mm2

sigm.VGE.d/(beta.LD/gamM.axl)= 154.71/237.04 = 0.653
Utilization level of the equiv. stress = 65.3 %

>> The analysis sigm.VGE.d/(beta.LD/gamM.axl) <= 1 is met

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Short-term deformation of the pipe (with live load)

| | | |
|---|---|---|
| Short-term young's modulus | E-Rohr | =210000. N/mm2 |
| Pipe stiffness | SR | = 0.642 N/mm2 |
| Bedding stiffness | SBh | = 12.000 N/mm2 |
| System stiffness Pipe/Soil | VRB | = 0.053 |
| Deflection of the pipe | delta-d | = 1.29 mm |
| under maximum loading | delta-d | = 0.13 % |
| admissible deflection | zul.delta | = 3.0 % |

W*** Kappa1: Delta_v = 0.13 not allowed; calculation with 1.0

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Stahlvortriebsrohre DN 1000 LM101

Stability analysis acc. to section 9.4.4 (Buckling safety)

| | | | |
|---|---|---|---|
| Puncture coefficient (Graph D10) | alpha-D | = | 6.784 |
| Reduction factor (Graph D11) | kappa-nue2 | = | 0.836 |
| Reduction factor (Graph D12) | kappa-a2 | = | 0.822 |
| Reduction factor (Graph D13) | kappa-a1 | = | 0.884 |
| Reduction factor | kappa-a=kappa-a1*kappa-a2 | = | 0.727 |
| Ring stiffness S0 of the pipe | | = | 0.080 N/mm2 |
| Calc.value, pipe stiffness S.R | | = | 0.642 N/mm2 |
| Crit. buckling stress, earth pressure ! | krit.qv | = | 4637.0 kN/m2 |
| Crit. buckling stress, water pressure ! | krit.pw | = | 0.0 kN/m2 |
| Total loading (for max HW) ! | massg.qv | = | 25.5 kN/m2 |
| Compression at bottom ! | vorh.pe | = | 0.0 kN/m2 |
| Exis. buckling safety ! | vorh.gamma | = | 182.2 |
| Req. safety against buckling ! | erf.gamma | = | 2.5 |

Buckling analysis in axial direction in the construction state

Raw data:

| | | | |
|---|---|---|---|
| Length of the pipe | L.ror | = | 10.00 m |
| Wall thickness, equal all around | t | = | 16.6 mm |
| Inner diameter | Di | = | 982.8 mm |
| Mean radius | Rm | = | 499.7 mm |
| Cross-section area | A.ror | = | 0.0521 m2 |
| E-Modulus, axial | E.axl | = | 150000.0 N/mm2 |
| Part. safety factor for axial member resis. | gamM.axl | = | 1.35 |
| Longitudinal compressive strength | f.k | = | 320.0 N/mm2 |
| Yield point | f.yk | = | 235.0 N/mm2 |
| Eccentricity | exz | = | 0.0 mm |

Relations :

| | | | | |
|---|---|---|---|---|
| rm/t | = | 30.102 -> E.axl/(25.*f.yk) | = | 25.532 |
| L.ror/rm | = | 20.012 > 0.5*sqrt(rm/t) | = | 2.743 |

>> Criterion for long cylinder shell is met

Verification:

| | | | |
|---|---|---|---|
| Coefficient with eta=3.0 | C.x = C.xN | = | 0.580 |
| Coefficient set | C.x | = | 0.600 |
| Ideal buckling stress | sigm.xSi | = | 1808.825 N/mm2 |
| related slenderness ratio | lambda.Sx | = | 0.360 |
| Reduction factor | k2 | = | 0.897 |
| Eccentricity present= 0.000, admissi. | | = | 3.320 mm |
| reduced reduction factor | red k2 | = | 0.897 |
| Partial safety factor | gamma.M2 | = | 1.224 |
| Real buckling stress | sigm.xSR | = | 172.150 N/mm2 |

Analysis under the max. admissible jacking force F.j = 2406.2 kN

| | | | |
|---|---|---|---|
| sigm.vor | = sigm_max | = | 172.150 N/mm2 |
| sigm.vor/sigm.xS,R = 172.150/172.150 | | = | 1.000 |
| Utilization level of the buckling stress | | = | 100.000 % |

>> Analysis sigm.vor/sigm.xS,R <= 1 is met

Stahlvortriebsrohre DN 1000 LM101

Soil and jacking data in the operation state

**SOIL DATA:**

Decisive soil type according to GW312/A161-Tab.1: soil group G1

The soil groups signify
Group 1: non-cohesive sands and gravel
Group 2: slightly cohesive sands and gravel
Group 3: cohesive mixed soils and silt
Group 4: cohesive soils

Pipe jacking in loose sediments
with support angle 2alpha = 180 Deg.
Unit weight above water Gamma-numerical = 1.00 kN/m3
Unit weight below water Gamma-buoyancy = 11.00 kN/m3

EarthPressure ratio above pipe crown K1 = 0.400
below pipe crown K2 in operation state = 0.463
Angle of internal friction Phi' = 32.50 Deg.
Friction angle in the shear joint Del' = 16.25 Deg.
Packing density in operating state D = 0.40
1. Factor for deform. modulus f1 = 0.40
2. Factor for deform. modulus in OS f2 = 1.00
Deformation module in operat. state E.B = 20.00 N/mm2

Reduction factor for arching in the operation state Kappa = 0.825
Reduction factor for arching
under loading in the operation state Kappa.0 = 0.672

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CALCULATION OF THE OPERATIONAL STATE (OS)

Load assumptions:
Soil cover height h = 3.00 m
Traffic load type = LM1 Load model
No ground water

**LOAD DATA**

Soil loads without buoyancy
Vertical earth load ev = 2.5 kN/m2
Surcharge p0 = 0.0 kN/m2
Horizon. earth load eh = 1.4 kN/m2
Foundation reaction pressure
(ev - eh) * k* = eh* = 0.8 kN/m2
Under consideration of gamma-buoyancy up to min. groundwater level
with k* = 0.698
Traffic loads
Traffic load p = 18.63 kN/m2
Impact coefficientwir.phi = 1.20
Impact coefficient phi0 = 1.20
statically acting pV = 22.4 kN/m2
statically acting pH = 3.0 kN/m2
Foundation reaction pressure
pV * k* = ph* = 15.6 kN/m2

Maximum total loading qv = 24.8 kN/m2
qh = 4.4 kN/m2
qh* = 16.4 kN/m2

Stahlvortriebsrohre DN 1000 LM101

| Section | | Springline | Pipe crown | Pipe base |
|---|---|---|---|---|
| **Cross-section values:** | | | | |
| Area | (cm2/m) | 166.00 | 166.00 | 166.00 |
| Resistance moment | (cm3/m) | 45.93 | 45.93 | 45.93 |
| Correction factor alpha.KI | | 1.01 | 1.01 | 1.01 |
| Correction factor alpha.KA | | 0.99 | 0.99 | 0.99 |

**Stress resultants acc. to section 7 and 8**

| | | | |
|---|---|---|---|
| Moments (kNm/m): | | | |
| M.G = (Dead load ) | -0.142 | 0.125 | 0.230 |
| M.w = (WaterCont./Groundw.) | -0.273 | 0.240 | 0.440 |
| M.ev = (Soil load vertical ) | -0.155 | 0.155 | 0.155 |
| M.eh = (SoilLoad horizontal) | 0.086 | -0.086 | -0.086 |
| M.eh*= (Foundation reaction) | 0.040 | -0.035 | -0.035 |
| M.pV = (Live load vertical ) | -1.396 | 1.396 | 1.396 |
| M.pH = (LiveLoad horizontal) | 0.189 | -0.189 | -0.189 |
| M.ph*= (Traffic found.react) | 0.811 | -0.706 | -0.706 |
| M.auf= (Buoyancy ) | 0.000 | 0.000 | 0.000 |
| Sum M.q = (total load) | -0.840 | 0.899 | 1.205 |
| M.Gk (Sum permanent load ) | -0.444 | 0.398 | 0.704 |
| M.Qk (Sum variable load ) | -0.396 | 0.501 | 0.501 |
| M.Gd=gamma.G*M.Gk=1.35*M.Gk | -0.600 | 0.538 | 0.950 |
| M.Qd=gamma.Q*M.Qk=1.35*M.Qk | -0.534 | 0.676 | 0.676 |
| M.Ed = M.Gd + M.Qd | -1.133 | 1.214 | 1.626 |
| Normal forces (kN/m): | | | |
| N.g = (Dead load ) | -1.023 | 0.163 | -0.930 |
| N.w = (WaterCont./Groundw.) | 0.537 | 1.561 | 1.963 |
| N.ev = (Soil load vertical ) | -1.237 | 0.000 | 0.000 |
| N.eh = (SoilLoad horizontal) | 0.000 | -0.690 | -0.690 |
| N.eh*= (Foundation reaction) | 0.000 | -0.221 | -0.221 |
| N.pV = (Live load vertical ) | -11.172 | 0.000 | 0.000 |
| N.pH = (LiveLoad horizontal) | 0.000 | -1.514 | -1.514 |
| N.ph*= (Traffic found.react) | 0.000 | -4.503 | -4.503 |
| N.auf= (Buoyancy ) | 0.000 | 0.000 | 0.000 |
| Sum N.q = (total load) | -12.896 | -5.203 | -5.894 |
| N.Gk (Sum permanent load ) | -1.723 | 0.813 | 0.122 |
| N.Qk (Sum variable load ) | -11.172 | -6.017 | -6.017 |
| N.Gd=gamma.G*N.Gk=1.35*N.Gk | -2.326 | 1.098 | 0.165 |
| N.Qd=gamma.Q*N.Qk=1.35*N.Qk | -15.083 | -8.122 | -8.122 |
| N.Ed = N.Gd + N.Qd | -17.409 | -7.025 | -7.957 |

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Stahlvortriebsrohre DN 1000 LM101

| Stress verification (characteristic) according to section 9.4.3 (N/mm2) | | | | |
|---|---|---|---|---|
| Sigma.M inside = M*alfa.I/W | -18.3 | 19.6 | 26.2 | |
| Sigma.M outsde = M*alfa.A/W | 18.3 | -19.6 | -26.2 | |
| Sigma.N = N/A | -0.8 | -0.3 | -0.4 | |
| exis.Sigma inside from N+M! | -19.1 | 19.3 | 25.9 | |
| exis.Sigma outside from N+M! | 17.5 | -19.9 | -26.6 | |

| Stress verification (design) according to section 9.4.3 (N/mm2) | | | |
|---|---|---|---|
| Sigma.M inside = M*alfa.I/W | -24.7 | 26.4 | 35.4 |
| Sigma.M outsde = M*alfa.A/W | 24.7 | -26.4 | -35.4 |
| Sigma.N = N/A | -1.0 | -0.4 | -0.5 |
| prov. Sigma inside from N+M! | -25.7 | 26.0 | 34.9 |
| prov. Sigma outsde from N+M! | 23.6 | -26.9 | -35.9 |
| adm. Beta.BZR | 320.0 | 320.0 | 320.0 |
| adm. Beta.D | 360.0 | 360.0 | 360.0 |
| Safety coefficients: | | | |
| Gamma provided | 12.31 | 11.19 | 8.33 |
| Gamma required | 1.00 | 1.00 | 1.00 |

Long-term deformation of the pipe (with live load)

| | | |
|---|---|---|
| Longterm Young modulus | E-Rohr =210000. N/mm2 | |
| Pipe stiffness | SR = 0.642 N/mm2 | |
| Bedding stiffness | SBh = 12.000 N/mm2 | |
| System stiffness Pipe/Soil | VRB = 0.053 | |
| Deflection of the pipe | delta-d = 1.23 mm | |
| under maximum loading | delta-d = 0.12 % | |
| admissible deflection | zul.delta = 3.0 % | |

W*** Kappa1: Delta_v = 0.12 not allowed; calculation with 1.0

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Stability analysis acc. to section 9.4.4 (Buckling safety)

| | | | | |
|---|---|---|---|---|
| Puncture coefficient | (Graph D10) | alpha-D | = | 6.784 |
| Reduction factor | (Graph D11) | kappa-nue2 | = | 0.836 |
| Reduction factor | (Graph D12) | kappa-a2 | = | 0.822 |
| Reduction factor | (Graph D13) | kappa-a1 | = | 0.884 |
| Reduction factor | kappa-a=kappa-a1*kappa-a2 | | = | 0.727 |
| Ring stiffness S0 of the pipe | | | = | 0.080 N/mm2 |
| Calc.value, pipe stiffness S.R | | | = | 0.642 N/mm2 |
| Crit. buckling stress, earth pressure ! | | krit.qv | = | 4637.0 kN/m2 |
| Crit. buckling stress, water pressure ! | | krit.pw | = | 0.0 kN/m2 |
| Total loading (for max HW) ! | | massg.qv | = | 24.8 kN/m2 |
| Compression at bottom ! | | vorh.pe | = | 0.0 kN/m2 |
| Exis. buckling safety ! | | vorh.gamma | = | 186.7 |
| Req. safety against buckling ! | | erf.gamma | = | 2.5 |

Admissible jacking force F.j according to DWA-A 161: 2013

Initial data:

Segment number:
Calculaton of 1. segment of range after hydraulic jack

Alignment geometry:
The alignment segment is straight

Pipe geometry:
Length of indiviudal pipe =10.000 [m]
Outer diameter Da = 1016.0, smallest da.min = 1016.0 [mm]
Inner diameter Di = 982.8, largest di.max = 982.8 [mm]
Wall thickness t = 0.0166, smallest t.min = 0.0166 [m]
at the spigot end t.ror = 0.0166 [m]
minimum area A.R = 0.0521 [m2]

Pipe material:
E-modulus in axial dir. E.axl = 150000.0 [N/mm2]
Long. compres. strength f.k = 320.0 [N/mm2]
Mean tensile strength f.tm = 360.0 [N/mm2]
Numerical strength value f.d = 237.0 [N/mm2]
Partial safety factor for axial member resistance Gamma.M.axl = 1.35

Pressure transfer ring (DUER):
Number of DUERs per pipe joint n_duer = 0

Execution of construction work:
Partial safety factor for actions with longitudinal loading along the axis and transient design situation (Tab. 12) gamma.f.axl = 1.15
Jacking force, estimated V_estim = 6000. [kN]
Measured or assured angular tolerances if >= 0: none entered

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## Calculation

```
----------
Angular dev. due to alignment curvature  phi.R   =  0.000 [Degree]
Angular deviation due to control motions phi.St0 =  1.090 [Degree]
                                         phi.St  =  1.153 [Degree]

Maximum deviation of the pipe crown
from perpendicularity                              d.a.cal =    3.2 [mm]
hence bending due to fabrication tolerance phi.d.a.cal =  0.180 [Degree]
Calculated total bending per joint          phi.ges     =  1.153 [Degree]
Coeff. for max.adm.Sigma     alfa.DT =  1.0000
t.Rohr.min/t.DUER            kappa.t =  1.0000
max.adm.Sigma in the pipe    sigm_cal =  237.04 [N/mm2]

Compressive stress in pipe   sigm.max =  172.15 [N/mm2]
Coefficient                  alfa.b   =  0.6916
Coefficient                  alfa.phi =  0.0000
Deformation factor           kappa.ab =  0.5000
Deformation of the pipe      delta.sR =  5.74 [mm]
```

```
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Iteration n_iter =  0: **********************************
Joint gaping dimension       z_k =  0.281 von 1.0
Integral                         =  0.0058 [m2]
Ratio of sigm.max to sigm.0  = smaxds0 =  4.46
Estimated jacking force        V_estim =  6000.0 [kN]
Admissible jacking force       adm. F.j =  2406.2 [kN]

Result:
Estimated jacking force       VPRES    =  6000.0 [kN]
Admissible jacking force     adm. F.j =  2406.2 [kN]
Joint gaping dimension            z_k =   0.281 von 1.0
-------------------------------------------------------------------------

Number of errors: W =  3, E =  0, F =  0

Program Duro: End of calculation of _DURO.DUR
-------------------------------------------------------------------------
```