The Second Edition of European NO DIG Conference

Segrate (Milan), Italy
25TH May 2023

Paper 22

DWA-A 143-2 Static Calculation for the Rehabilitation of Drains and Sewers

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ABSTRACT: As an alternative to replacing existing pipelines, various renovation procedures offer significant advantages with respect to investment costs, environmental protection, and urban pollution. Depending on the procedure, it may well be possible to extend the service life, to match that of a replacement. A thorough study of the current stability and residual load capacity of the existing sewer is required, along with needs-based selection and dimensioning of the rehabilitation procedure. The German standard DWA-A 143-2 serves as a good basis for the necessary static calculations.
Increasingly European companies are conducting structural calculations of liners according to the DWA-A 143-2 standard.

1. Structural calculation of buried pipes

Statical model of a buried pipe is not the pipe solely – it is a pipe-soil-system (PSS). The structural calculation concept of buried pipes depends on V_{RB}, the stiffness of the PSS. V_{RB} decides weather the PSS is rigid or flexible; it depends on pipe geometry, material, and soil beneath the pipe.

$$V_{RB} = \frac{8 \times S_0}{S_{Bh}} \qquad [1]$$

S_0 *Stiffness of the pipe*
S_{Bh} *Horizontal bedding stiffness of the soil*

If $V_{RB} > 1$, we speak of rigid PSS. Earth loads concentrate mostly on the pipe and their intensity reduces right beneath it, see **Figure 1**. The pipe takes over most of the vertical loads. Concrete, reinforced concrete and stoneware pipes always result in a rigid PSS. Load concentration factor λ_R depends on bedding, stiffness ratio etc.

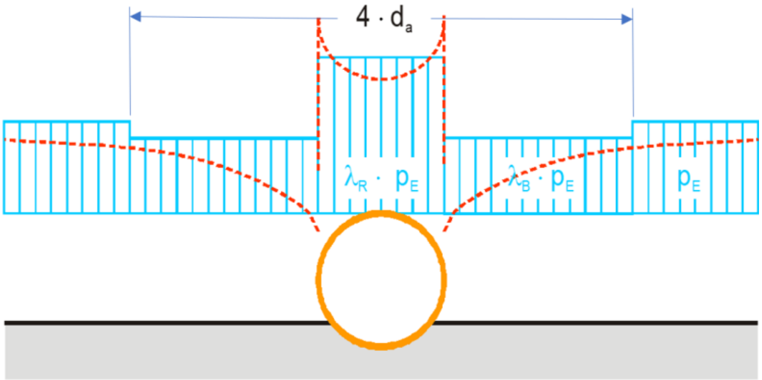

Figure 1. Rigid Pipe-Soil-System

If $V_{RB} \leq 1$, the PSS becomes flexible. The pipe deforms enough to transmit most of the loads on the nearby soil but only in usability limits. After $4d_a$ (outer diameter), the native soil is not disturbed by pipe anymore.

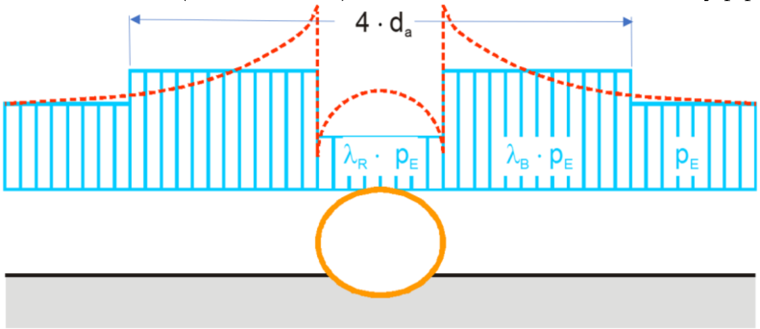

Figure 2. Flexible Pipe-Soil-System

Besides stress verifications for the pipes in all PSS, the pipes in a flexible PSS must be verified for stability (buckling) and a deformation proof must be conducted.
Rehabilitation of drains and sewers deals mostly with flexible PSS.

2. Condition of the host pipe

Condition assessment is based on the worksheet DWA-A 143-2 [2], which governs the static calculations for the rehabilitation of drains and sewers using lining and assembly methods. For a basic assessment of the stability of the sewers to be rehabilitated, three basic and one informative host pipe conditions (HPC) are differentiated.

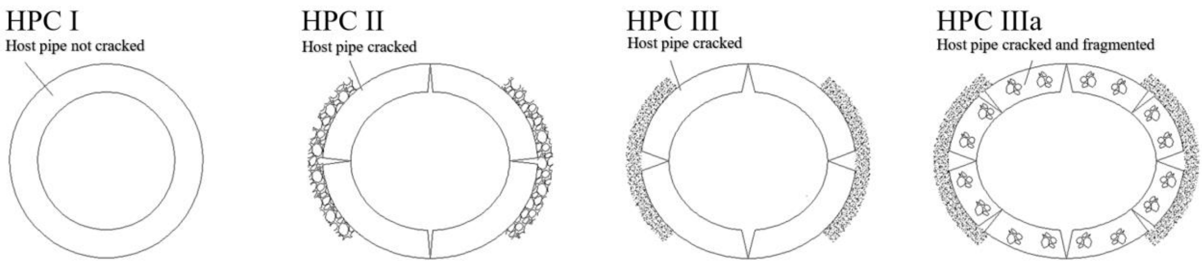

Figure 3: Host pipe conditions I, II, III and IIIa, source [3]

HPC I: The host pipe alone can bear all external loads. No cracks occur except for capillary cracks. The liner only ensures sewer tightness and is stressed by the groundwater that seeps through the untight sewer wall, **Figure 4**.

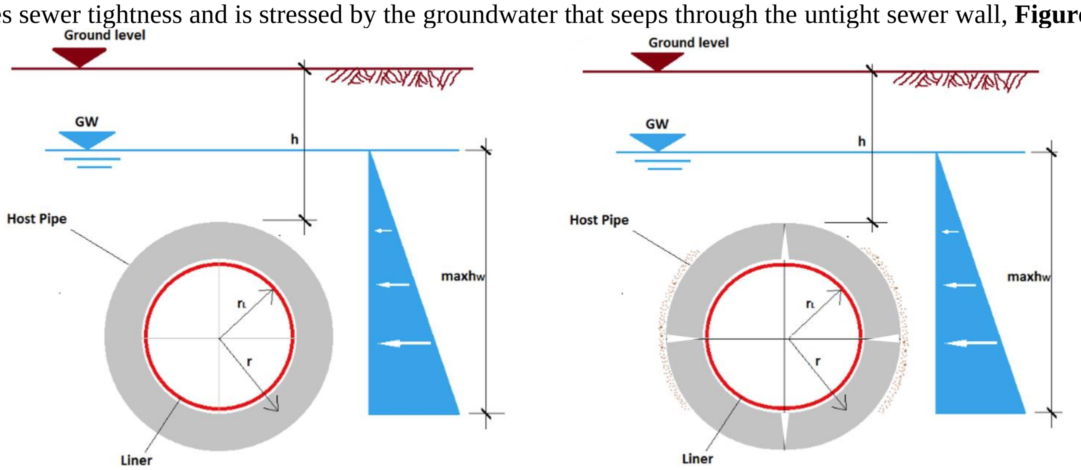

Figure 4: HPC I (left), HPC II (right)

HPC II: The host pipe alone cannot bear the external loads. Longitudinal cracks occur at four points on its circumference (crown, springline and invert). The formed quarter-shells are ovalizing, lowering the vertical diameter of the pipe and broadening the horizontal diameter of the pipe. This results in pushing the springlines of the pipe into the soil beneath the pipe and activating it as a support of the longitudinally cracked pipe. The new system is called the host pipe-soil-system, which has its analogy with the PSS in buried pipes. In HPC II the host pipe-soil-system is structurally sound and can bear all external loads. As in HPC I, the liner only ensures sewer tightness and is stressed by the groundwater that seeps through the untight sewer wall. Unlike to HPC I, an oval, pre-formed liner may be required.

HPC III: The crucial difference in comparison to HPC II is that the stability of the host pipe-soil-system is no longer verifiable. Besides bearing groundwater loads, the liner must at least partially cope with all influences such as earth and traffic loads. The influences on the liner in HPC III are generally much greater than in HPC I and II.

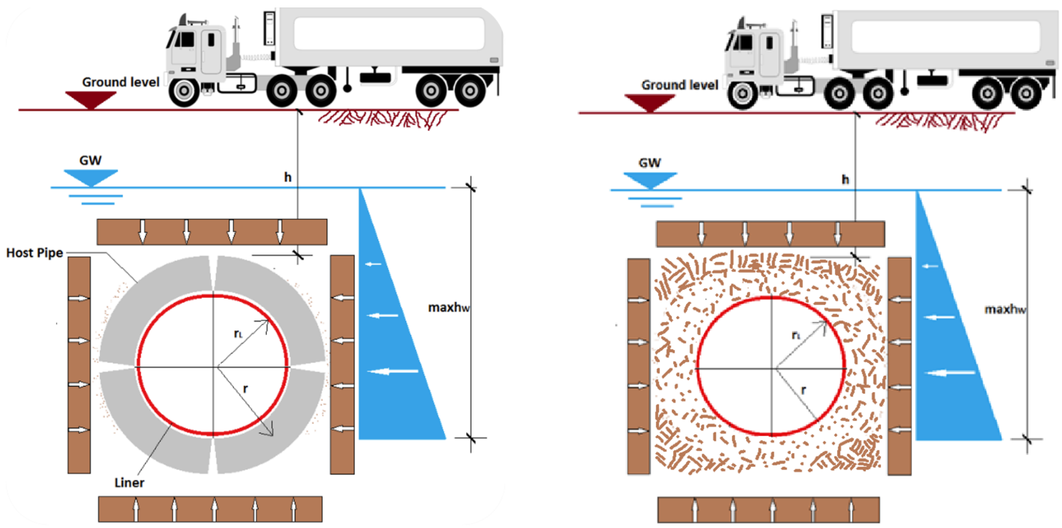

Figure 5: HPC III (left), HPC IIIa (right)

HPC IIIa: This HPC is included in the informative annex K of the work sheet [2]. It is assumed in this case that the quarter shells between the joints (longitudinal cracks) of the host pipe do not remain intact and are fragmented or break further, thus eliminating the supportive effect of the host pipe. The load transmission in the host pipe pressure zones, especially springlines, is not possible due to insufficient strength of the host pipe. The liner is calculated as a buried pipe (elastically bedded ring) according to [1].

3. Imperfections and eccentricity

Depending on the condition of the host pipe, imperfections must be applied on the liner. It must be assumed, that the cross-section of the liner will differ from the inner contour of the host pipe or idealized host pipe. Work sheet [2] considerers three types of imperfections:

Local imperfection w_V is a short-waved bump and must fulfill different tasks in statical regard. Firstly, it occurs in hoses due to humps in the wall of the host pipe, especially at the installation state before curing of the liner takes place. Secondly, it covers fluctuations of the mechanical and geometrical liner material properties – local decrease of stiffness and/or wall-thickness. Finally, it is a trigger of the decisive buckling case for the stability verification in a structural calculation according to the 2nd order theory.

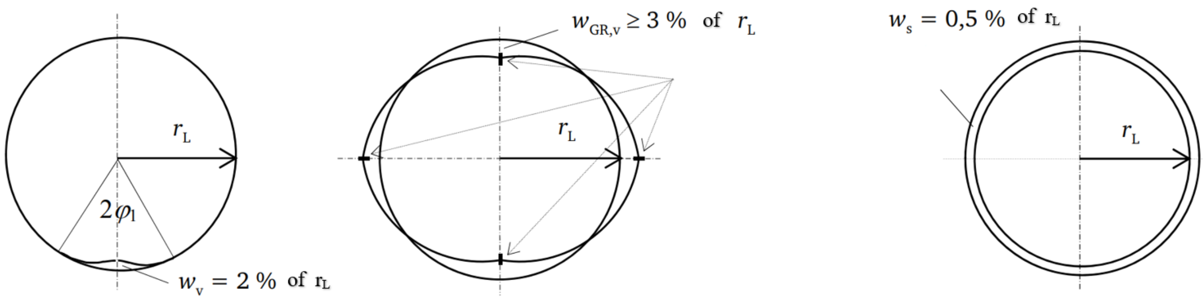

Figure 6: Local imperfection (left), ovalisation (middle), annular gap (right)

Ovalisation w_{GRV} is the form that the host pipe takes after it is cracked in crown, invert and springlines. This way the installed liner adopts the ovalized form of the host pipe.

Annular gap w_S occurs through shrinking or expanding of the resin in liner material or by shrinking of the grout after grouting the annulus. This imperfection discontinues the contact between the liner and the host pipe or between the liner and the grout. It makes great impact to the liner when high groundwater levels are present.

The work sheet [2] prescribes minimal imperfections values depending on rehabilitation method and shape of the host pipe and/or liner.
Figure 6 shows imperfections for circular profiles.
The local imperfection on an oval or egg-shaped profile is placed on the flat side. Ovalisation is considered as an increase of the local deformation. Annular gap is considered as a degree of constant shrinkage.
Other non-circular profiles must be separately considered. The place of local imperfection must be chosen carefully and if necessary, on different places. **Figure 7** shows the application of local imperfection on an oval and special shape profiles.

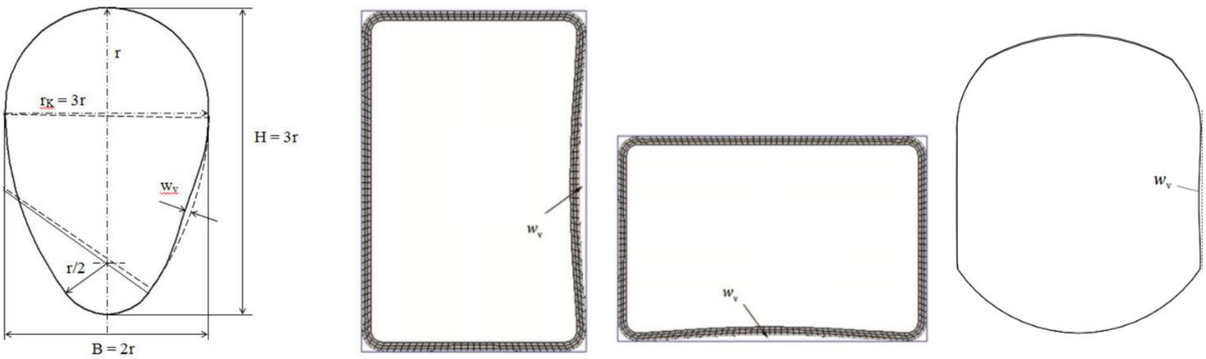

Figure 7: Standard oval shape (left), rectangular profiles FE-simulation (middle), beam model (right)

Eccentricity is the distance of the rotation point (crown joint) to the mid-axis of the host pipe, see **Figure 8**. It is applied in in the HPC III only. The greater the value the better the condition of the host pipe. Depending on the condition of the host pipe, following values are recommended:

- e_G/t = 0.25 for very damaged pipes – visible spalling, low strength, significant corrosion
- e_G/t = 0.35 (standard case) for normal state pipes – almost no spalling, higher strength, low corrosion
- e_G/t = 0.45 for pipes in good condition – no spalling, high strength, no corrosion, host pipe as new

t – wall thickness of the host pipe
e_G – eccentricity

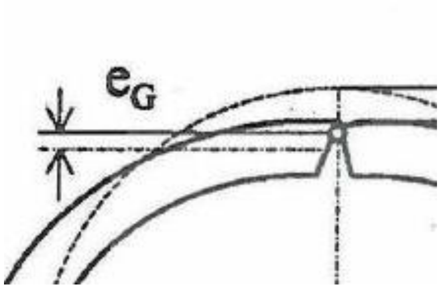

Figure 8: Eccentricity

4. Loads

Each liner must be designed for the groundwater level of 1.5 m above the liner invert or 10 cm above the liner crown – the higher value must be applied. This ensures the basic stability of the liner. Besides groundwater and possible inner pressure and/or temperature change in HPC I and II, in HPC III and IIIa earth and traffic loads must be considered at designing the liner.
Earth loads depend on the cover depth of the host pipe and specific gravity of the soil. The increase of the earth pressure is assumed to be linear in depth.
Traffic loads have their greatest intensity on the ground level and generally decrease with depth. Standard traffic loads in work sheet [2] are taken from DIN EN 1991-2:2010-12 and adjusted for the static calculation of pipes and liners.
The representative for road traffic loads is the load model 1 (LM 1) with its total weight of 60 tons. Four wheels of 150 kN each are pressing the 0.4x0.4 m imprint in first lane and four wheels of 100 kN each are pressing the 0.4x0.4 m imprint in second lane, see **Figure 9**. The stresses due to LM 1 are given in diagram forms depending

on host pipe length, cover depth and diameter. The impact factor is contained in the diagrams. Fatigue verification is required for cover depths lower than 1.5 m.

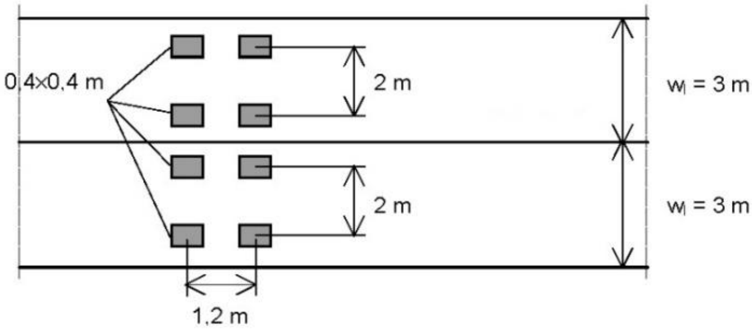

Figure 9: LM 1 according to DIN EN 1991-2:2010-12

The representative for the railway traffic loads is the load model 71 (LM 71). Values in the work sheet [2] are available for the earth covers higher than 1.1 m. Railway loads in shallow depth can be distributed according to DIN EN 1991-2. Impact factor depends on cover depth and clear width of the profile. Fatigue verification is required for cover depths lower than 5.5 m. Loadings due to LM 71 are shown in Figure 10.

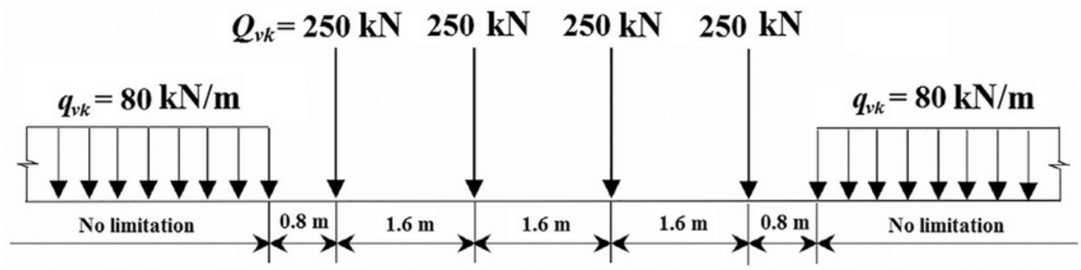

Figure 10: LM 71 according to DIN EN 1991-2:2010-12

Airplane loads are considered in a table of the work sheet [2] and as a diagram. They depend on airplane weight and earth cover. Impact factor of 1.5 is not considered in the table nor diagram. Local airports may consider different aircrafts.

5. General design form

The semi probabilistic partial safety concept (e.g., the Eurocode) is state of the art and as such implemented in work sheet [2]. General design form for stresses looks like this:

$$\frac{S_d}{R_d} \leq 1 \qquad [2]$$

S_d *Design value of the influences*
$S_d = \Sigma\ (Influence\ x\ partial\ safety\ factor\ \gamma_F)$
R_d *Design value of the material resistance*
$R_d =$ *Material strength divided by partial safety factor for specific material* γ_M

Table 1: Partial safety coefficients γ_F for influences

Influence	γ_F
Permanent loads (Dead load, Earth loads, Surface loads, etc.)	1.35
Variable loads (Traffic loads except road traffic load, Groundwater)	1.5
Road traffic loads	1.35
Short term floodwater	1.1
Internal pressure (including pressure surge)	1.5
Inspection pressure	1.2
Temperature change	1.1
Imposed deformations	1.1

Table 2: Partial safety coefficients γ_M for material resistance

Material	γ_M

Plastic liners, hardened on site	**1.35**
Prefabricated plastic liners (extrusion or similar)	**1.25**
Cement liner	**1.5**
Stainless steel	**1.15**
Resistance with a favourable effect (e.g., imposed liner deformations in HPC III)	**1.0**
Concrete and vitrified clay host pipes for the proof of pressure zones (eq. 102)	**1.5**

Table 3: Coefficients for combinations ψ

Combination	**ψ**
Temperature change combined with groundwater	**0.7**
Actual groundwater combined with earth and traffic loads	**0.9**
Replacement load for groundwater combined with earth and traffic loads	**0.7**

Example:

Design stress in liner invert:	$\sigma_{t,d}$	=	21.5 N/mm²
Material Strength characteristic:	$\beta_{t,c}$	=	60 N/mm²
Partial safety factor material:	γ_M	=	1.35
Material Strength design:	$\beta_{t,d}$	=	60/1.35 = 44.4 N/mm²

Stress check: $\frac{\sigma_{t,d}}{\beta_{t,d}} = \frac{21.5}{44.4} = 48.4\ \% < 100\ \%$

6. Verifications

Stresses

Cross-section forces are computed by using the appendix D for HPC I and II and appendix E for HPC III. The coefficients provided in those appendixes are allowing us to determine the moments and normal forces in the liner wall and eventually computing the normal stresses occurring in liner. The stress verification is conducted considering the design values of the loads and material properties.
Shear stresses require the information of a shear strength. If no test data are available, it is allowed to apply the shear strength of $\tau_{u,d} = 8/\gamma_M = 5.9$ N/mm².
Formulas for computing stresses provided in work sheet [2] will not be documented in this presentation.

Deformations

For the deformation proof characteristic loads and material properties are considered. The total deformation is calculated as a sum of elastic deformation, half of the local imperfection and ovalisation. The elastic deformation is the diameter change at loading.

$$\delta_v = \delta_{v,el} + \frac{\omega_v}{2} + \omega_{GR,v} \qquad [3]$$

As a limit for the host pipe and the liner is recommended that the total deformation does not exceed 10 %.

- $\delta_v < 10\ \%$

Elastic deformation should be limited as follows:

- $\delta_{v,el} < 3\ \%\ for\ HPC\ I\ and\ II\ (groundwater)$
- $\delta_{v,el} < 6\ \%\ for\ HPC\ III\ (earth\ and\ traffic\ loads)$
- $\delta_{v,el} < 2\ \%\ or\ w_{el} < 10\ mm\ for\ German\ railway$

Stability

In work sheet [2] diagrams are provided that make calculation of stability possible without the use of software. Depending on imperfections of the liner, different diagram can be used for checking the stability.

Pressure transmission in the host pipe springline

It is necessary to ensure the pressure transmission in the springline of the host pipe in HPC III. If the proof provided in work sheet [2] is not fulfilled, the liner must be designed according to appendix K and HPC IIIa.

Soil limit stress

If high lateral forces are required to stabilize the system, following condition must be fulfilled:

$$max q_h = 0.75 \times K_p \times \lambda_B \times p_E$$

$$K_p = tan^2(45^\circ + \frac{\varphi'}{2})$$

$\lambda_B = 0.83$
p_E *Soil pressure at the springline*

This verification is often hard to fulfill at shallow installations of the liner and heavy traffic loads. If a HPC III is given, then this proof must already be provided by the classifier of the host pipe.

Fatigue proof
Must be generally provided when traffic loads are present. Required for:

- Road traffic LM1 and earth cover < 1,5 m (calculated for LM 3 – lighter model)
- Railway traffic LM71 and earth cover < 5.5 m
- Airplane traffic in all depths

Manufacturer must determine the amplitude of the material for

- 10^8 load cycles required for LM 71
- $2x10^6$ load cycles required for LM 3 (road traffic load)

7. Software aided design

For a manual calculation one would need several hours even with a help of a spread sheet to determine a required wall-thickness of the liner. The margin for error is also very great.
Today engineering is not imaginable without the use of computers. All static calculations for verifications mentioned above are simply conducted by modern software solutions. A representative of such is widely spread program for static calculation of buried pipes, manholes and liners IngSoft EasyPipe. Static calculation of HPC III liner is done in less than five minutes. IngSoft EasyPipe with its A143-2 module is a parameterized FEA program developed for the static calculation of circular and standard DIN egg-shaped liners in HPC I, II and III. Figure 11 shows compressed results of the HPC III calculation for a circular profile.

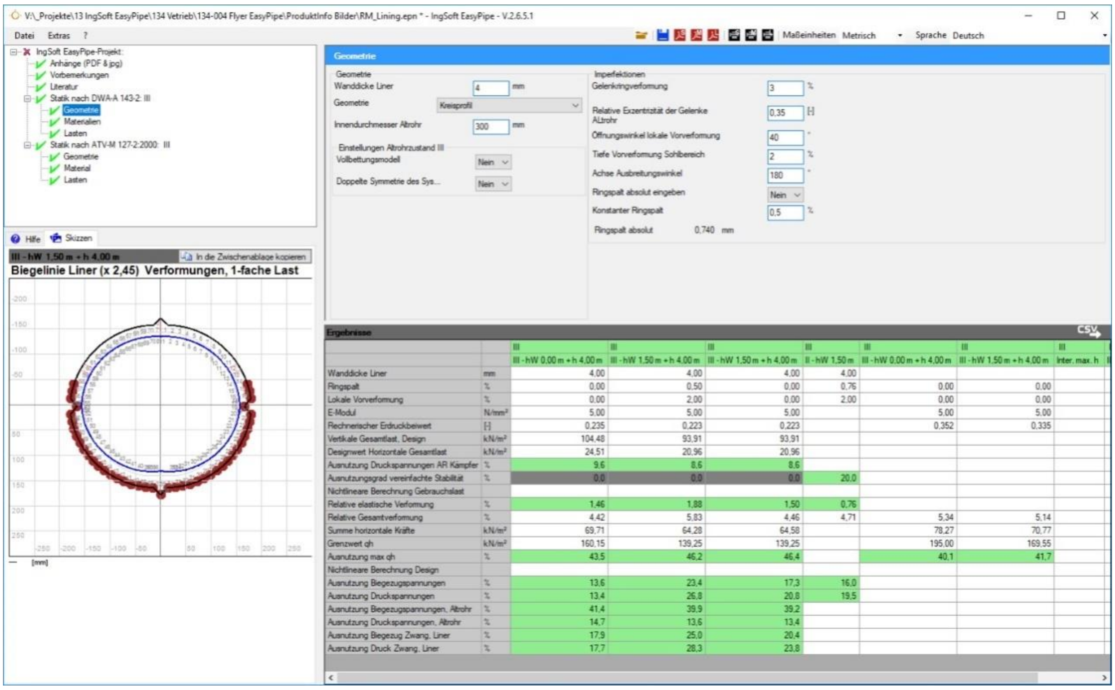

Figure 11: Mask of the program IngSoft EasyPipe

For host pipes categorized in HPC IIIa and profiles with geometry that differs from circular or DIN egg-shaped, special FEA programs for general purpose must be used. Some of them are Ansys, Abaqus and Nastran.

8. Conclusion

The worksheet DWA-A 143-2 [2], published in July 2015, provides a sound basis for the preparation of static calculations in the context of rehabilitation of buried sewers and canals.

In all load combinations liner must withstand the occurring stresses and keep its structural stability. The deformations must be kept in tolerable limits to ensure the serviceability of the liner.
In classification of the host pipe in HPC it must be determined weather the quarter shells between the cracks of the host pipe are structurally sound for the given loads.
To prevent a stability collapse of the whole host pipe-soil-system including the liner, the host pipe-soil-system should be verified prior to lining.
The work sheet [2] limits the bedding reaction pressure to prevent, especially at shallow covers, that the bedding reaction pressure exceeds the passive earth pressure that could be activated.

The liner module A143-2 of the program IngSoft EasyPipe conducts the described calculation in one computation run. Even a complex calculation of HPC III is easily done.
With right preparation of boundary conditions and assessing of correct rehabilitation parameters, an economic and safe design can be achieved.

9. REFERENCES

[1] German Association for Water, Wastewater and Waste, 2000-08. Worksheet ATV-DVWK A 127: Structural calculation of drains and sewers (2000-08).

[2] German Association for Water, Wastewater and Waste, 2015-07. Worksheet DWA-A 143-2: Rehabilitation of drainage systems outside buildings – Part 2: Static calculations for the rehabilitation of drains and sewers by lining and assembly methods.

[3] 3R Special 02/2016. Dietmar Beckmann, Heinz Doll, Vladimir Lacmanović (2016). Rehabilitation of large profiles lacking long-term stability.