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Numerical and experimental investigations on the behaviour of leachate collection pipes in waste disposal engineering

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ABSTRACT: The paper presents the essential results obtained from the numerical and experimental investigations on the mechanical behaviour of leachate collection pipes which are applied in waste disposal engineering. First, several short-term model tests on PEHD pipes were done under different conditions. With the help of the measured displacements from the model tests the numerical model using FEM was calibrated. Based on these results, numerical parameter study was carried out to research the behaviour of PEHD drainage pipes under practical working conditions. Many varying factors, such as short- and long-term stiffness, different base sealing materials, geometrical profiles of pipes etc were included in the study.

1 INTRODUCTION

PEHD drainage pipes have been widely used to build leachate collection systems in waste disposal engineering. As illustrated in Figure 1, normally these drainage pipes have circle cross section (250 to 300 mm diameter) and are embedded in coarse drainage gravel. With the help of this system the leachate of the waste disposal should be collected, and if needed let into cleaning plants.

Waste cover has normally a height of up to 60 m. The resulting heavy loads in pipe zones must be partly carried by the pipes. The part of loads carried by the embedded pipes depend upon many factors, above all the stiffness of pipe material.

It is well known that PEHD material is more flexible than other materials such as stoneware. Under the loading of the waste cover, PEHD pipe may deform considerably (see figure 2). This problem is especially critical, if the long-term state is considered. In this situation, the stiffness of PEHD pipes may decrease considerably, especially at high

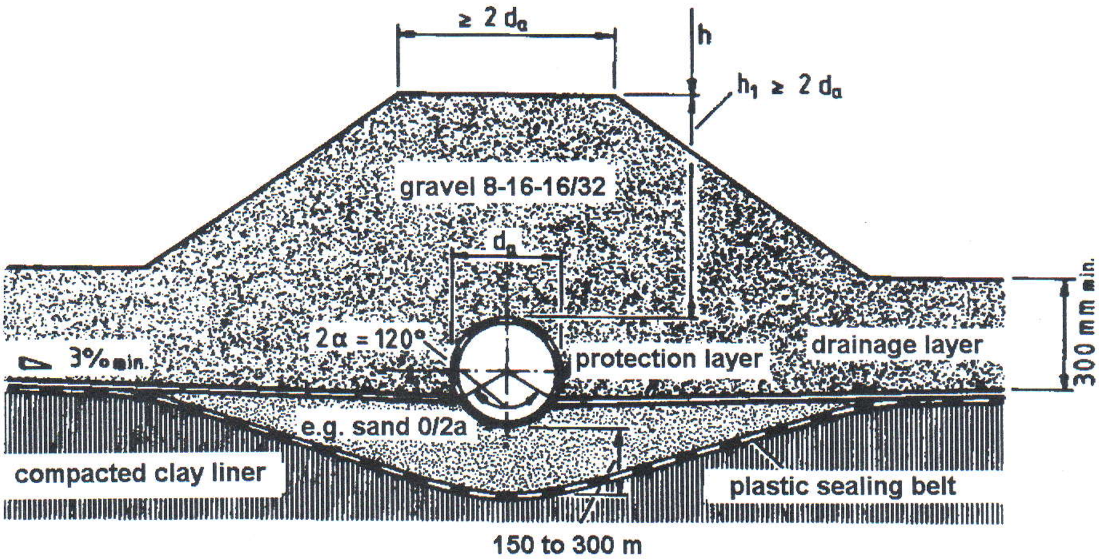

Figure 1. Cross section of constrution, leachate collection pipe zone, according to DIN 19 667.

temperature. As reported, the temperatur inside waste disposal may rise up to about 80°C. This time-dependent deformation of PEHD pipes could lead to the load distribution between the pipe and the neighbouring coarse gravel.

Previous research indicates (e.g. Zanzinger et al 1992), that this complicated interaction can't be properly described by means of routine design methods for shallow buried pipes. A deep insight into this complicated interactive action could be gained by using a calibrated numerical model.

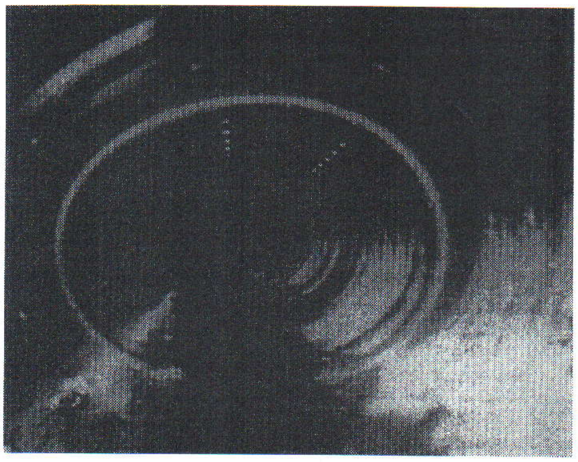

Figure 2. Deforming of a PEHD drainage pipe, photo from canal driving.

On the other side, compacted clay liner or asphaltic concrete have been normally used as sealing layer. The analysis of pipe damage indicates that many damage cases in pipes were caused by improper construction of laying pipes on sealing layers. It becomes more difficult, if asphalt concrete is applied. Therefore, it has been proposed from construction companies, to use rectangular drainage pipes instead of circular pipes, see figure 3. The applicability of this draft should be theoretically and experimentally researched.

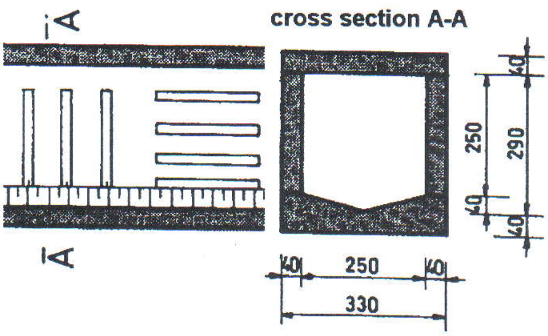

Figure 3. Arrangement of rectangular drainage pipe, an example, dimension in mm.

2 LARGE SCALE MODEL TESTS AND CALIBRATION OF NUMERICAL MODEL

2.1 *Test conditions and set up*

The large scale model tests on PEHD drainage pipes were carried out by using a test box. In figure 4 the construction and dimensions of the box are illustrated. The model scale for drainage pipe zone is 1:1. The size and the geometry of the drainage pipe zone were determined according to DIN 19 667.

As the wall of the box is made of 22 mm thick shawl board, additionally strengthened by steel belts in three levels and jackets between them, it can be considered as stiff for the expected vertical static loading. Under the given boundary condition the horizontal deformation perpendicular to the cross section can be prevented in principle. In addition, the inner wall surface of the box was smeared. The smearing reduced the friction between wall and soils considerably. Based on these, the deformation state of the model tests can be seen as plane strain.

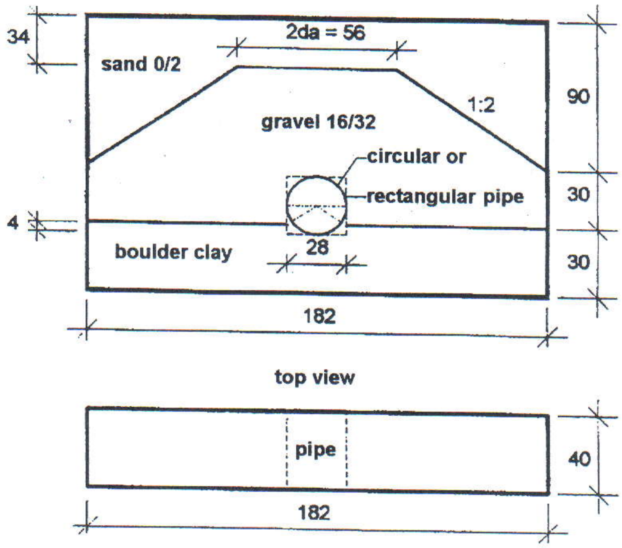

Figure 4. Cross section and top view of test box, dimension in cm.

As illustrated in figure 4, the tested PEHD drainage pipes (circular or rectangular) were laid on a compacted clay liner, modelling the base sealing layer. The pipe was surrounded by gravel material (16/32 mm) simulating the drainage medium. The thickness of this layer above the pipe was larger than twice the diameter of the tested pipes. Above this, one layer of loose compacted sand (0/2 mm) was used to replace waste material. The surcharge of waste material was applied by using a hydraulic press. The set up of model tests is illustrated in figure 5.

The total expected loading was raised step by step with an increment of 10 kN up to a pressure of 416 kN/m². This corresponds to a waste cover of 27.5 m. During the tests, the load-displacement curves were recorded for the following components:

-vertical displacements on top and foot of the pipe

-horizontal convergences of the pipe

-settlement of top loading plate.

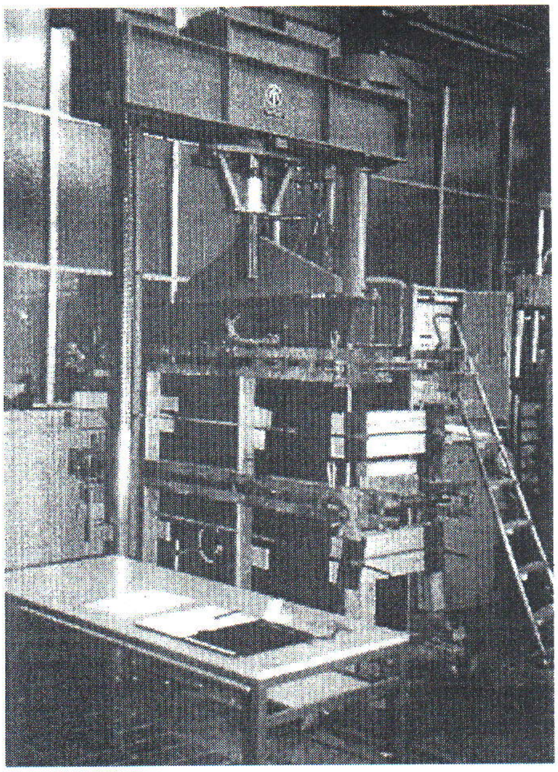

Figure 5. The set up of model test.

Table 1. Input parameters of five model tests

case	profile	s [mm]	h [m]	t [h]	E [MN/m²]	ν [-]
1	circular full wall	15.9	27.5	0.5	900	0.2
2	circular punched	15.9	27.5	2.5	800	0.2
3	circular slited	15.9	27.5	2.6	750	0.2
4	rectangular full wall	20.0	27.5	2.6	900	0.2
5	rectangular slited	20.0	27.5	2.6	750	0.2

s: wall thickness; h: waste cover; t: test duration.

2.2 *Test cases and material parameters*

In table 1, the input parameters of five model tests are given. The mechanical parameters of PEHD material (E and ν) in the table were determined from the pretests directly on PEHD pipes. Because of the short test duration the obtained results should be seen as short-term values.

The soil mechanical parameters in the model tests were evaluated from the known values and our experience, see table 2. They have been used in the numerical calculations for model calibration.

Table 2. Soil mechanical parameters

Soil type	γ [kN/m³]	Es [kN/m²]	E [kN/m²]	ν [-]	c′ [kN/m²]	φ′ [-]
boulder clay	18.0	6000	2500	0.4	30.0	25.0
gravel 16/32	20.0	22000	16000	0.3	0.0	35.0
sand 0/2	18.0	12000	7000	0.35	0.0	30.0

2.3 *Test results and calibration of numerical model*

In analysing the results of the model tests, comparison was made with the values from finite element calculation by using PLAXIS.

In figure 6, the tested and calculated load-displacement curves for the punched circular PEHD pipe (case 2) are put together. For all measured displacements, the calculated values are in good agreement with the test results. Similar results for the slited rectangular PEHD pipes can be observed in figure 7 (case 5).

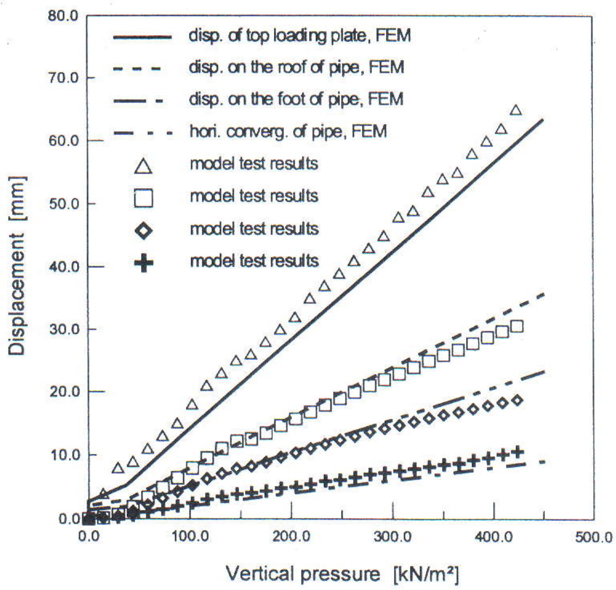

Figure 6. Comparision of model test results with finite element calculations, case 2.

Good agreements have been achieved for model test results and calculations of the other cases. This means that the interaction taking place in the PEHD pipe zone can be well simulated by using the applied numerical model.

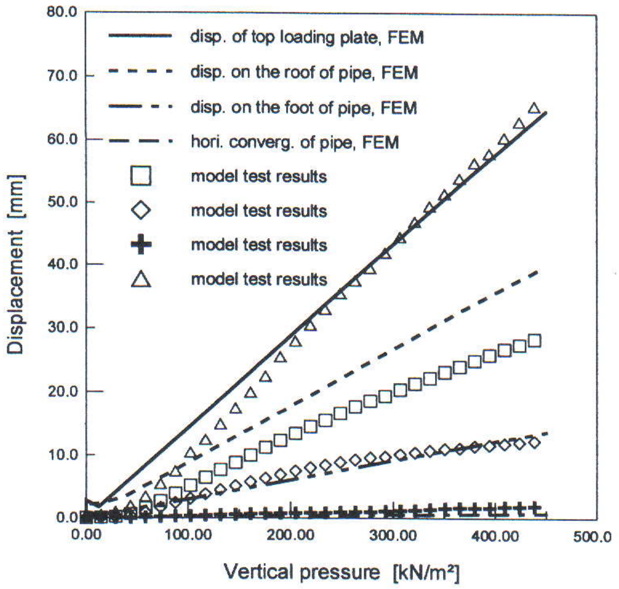

Figure 7. Comparision of model test results with finite element calculations, case 5.

1 NUMERICAL PARAMETER STUDY

1.1 Description of the problem

Two typical construction methods of PEHD drainage pipes are applied in practice, on compacted clay liner and on asphaltic concrete liner respectively. Based on figure 1, two corressponding calculation sections were chosen in the numerical parameter study.

The important factors influencing the interaction and bearing capacity of PEHD pipes are listed as follows:

-Base sealing material

-Short- and long-term stiffness of PEHD material

-Geometrical profile of the pipe

-Soil mechanical parameters

To investigate the influence of these input parameters and boundary conditions on the load redistribution in the drainage pipe zone, in total 10 cases were calculated for the slited PEHD pipes, see table 3. In terms of ATV-M127, 1996, the effects of time (short and long-term), temperature and loss of effective area arising from slits, have been taken into consideration in the assumed E-values of the pipes. The used soil mechanical parameters are listed in table 4.

1.2 Calculation results

Compacted clay liner as base sealing

In figure 8, the calculated distributions of principal

Table 3. Calculation cases in the parameter study

case	sealing	profile	d [mm]	s [mm]	Model	E [MN/m²]	ν [-]
1	CCL	C	280	15.9	S	750	0.2
2	CCL	R	280	20.0	S	750	0.2
3	CCL	C	355	32.3	S	700	0.2
4	CCL	R	355	32.3	S	700	0.2
5	CCL	C	355	32.3	L	71	0.25
6	CCL	R	355	32.3	L	71	0.25
7	AC	C	355	32.3	S	700	0.2
8	AC	R	355	32.3	S	700	0.2
9	AC	C	355	32.3	L	71	0.25
10	AC	R	355	32.3	L	71	0.25

CCL: compacted clay liner; AC: asphaltic concrete;
C: circular; R: rectangular; d: external diameter;
s: wall thickness; S: short-term; L: long-term

Table 4. Soil mechanical parameters used in the parameter study

Soil	γ [kN/m³]	E [kN/m²]	ν [-]	c′ [kN/m²]	φ′ [°]
waste material	15.0	470	0.4	5.0	27.5
compacted caly liner	18.0	2500	0.40	30.0	25.0
gravel 16/32	20.0	16000	0.30	0.0	35.0
asphaltic concrete	23.0	2000000	0.25	-	-

stress caused by a waste cover of 30 m in the pipe zone are put together for case 3, 4, 5 and 6.

By comparing the short-term state stresses of the rectangular and the circular pipe much higher stress concentrations are found out in the gravel zone on the top edge of the rectangular pipe. In the long-term state, however, the difference in stress concentration becomes smaller between the values for the circular and rectangular pipes.

In the long-term state the higher stresses in the gravel zone on the sidewall of the circular pipe can be put down to the load redistribution between pipe and surrounding soils. This results in considerable unloading of the circular pipe (see figure 9).

For rectangular pipe, load redistribution from short- to long-term states also takes place, but in some other way. The high vertical stresses on the vertical wall determined in short-term state and the low horizontal support from the wall give rise to a plastic zone in the drainage gravel. The resulting time-dependent plastic deformation leads to a movement of principal stress trajectory off the wall and further the enlargement of the plastic zone. This is accompanied by the reduction of stress directly

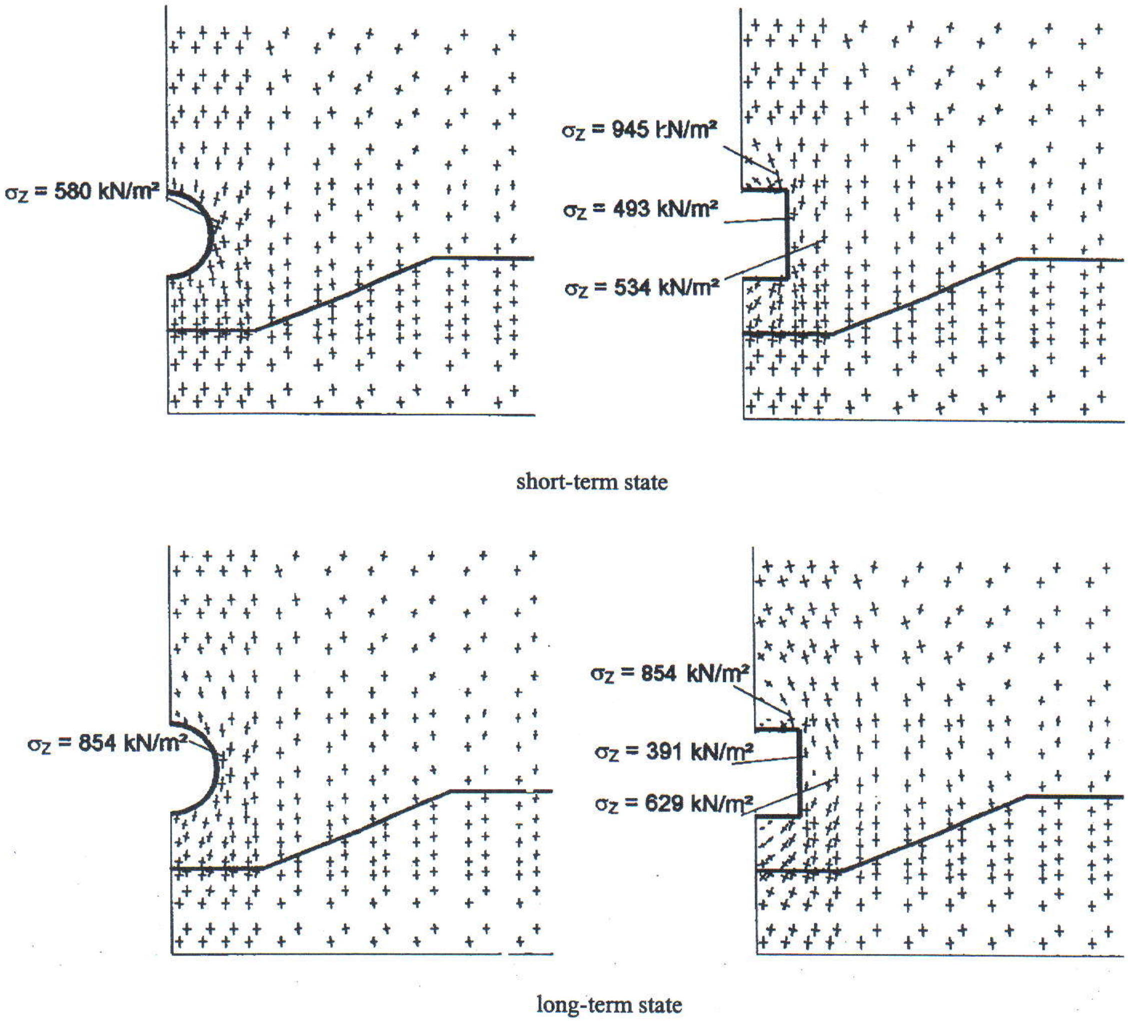

Figure 8. Calculated principal stress distributions for case 3 to 6.

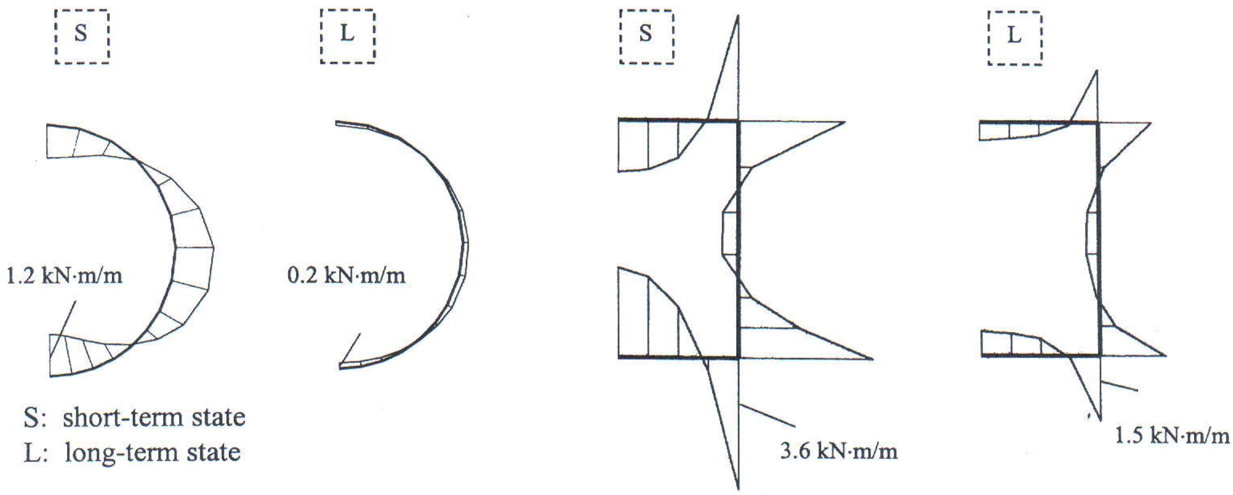

Figure 9. Calculated bending moments in pipe walls for case 3 to 6.

around the pipe. Because of the larger horizontal deformation compared with circular pipe, the bending moments in rectangular pipe are therefore much larger (see figure 9). The maximum normal forces in wall indicate no essential difference between circular and rectangular pipes and are therefore not illustrated.

Asphaltic concrete as base sealing

Similar tendencies concerning the load redistribution in the pipe zone from short- to long-term state for circular and rectangular pipes on asphaltic concrete were also observed from the calculated results.

Comparing the bending moments for rectangular pipes on compacted clay liner and asphaltic concrete liner (see figure 9 and 10), it may come to the result that the application of the rectangular PEHD drainage pipe on asphaltic concrete is better than on compacted clay liner.

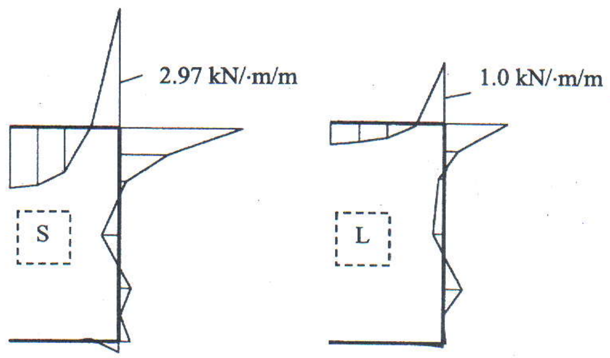

Figure 10. Calculated bending moments in pipe walls for case 8 and 10.

2 CONCLUSIONS

The comparision of model test results with numerical calculations indicate, that the interaction between pipe and neighbouring soils occurring in PEHD-pipe zone can be well simulated by using the applied numerical model.

The parameter study for PEHD drainage pipes under practical working conditions by using the calibrated numerical model shows, that for the pipes critical loading stage is in short-term state, whereas the large deformation of pipes may become a controlling factor for their working performance in long-term state.

As expected, independent of the applied base sealing material much higher stress concentrations have been calculated in the gravel zone around the rectangular pipe than around the circular pipe in short-term state.

In long-term state, the higher stresses in the gravel zone on the sidewall of circular pipe indicate clearly the load redistribution effect which resultes from the time-dependent creep behaviour of PEHD material.

For a rectangular pipe, however, large plastic zones off the sidewall result in the reduction of stresses in the gravel zone around the pipe. The occurring larger deformation give rise to large bending moments inside the wall.

Similar tendencies as on compacted clay liners have been determined by simulating pipes laid on asphaltic concrete liners. The study shows that by applying rectangular PEHD drainage pipe, asphaltic concrete seems to be a better choice than compacted clay liner.

It should be notified, that rectangular pipes can resist a waste overburden of appr. 20 m whereas circular pipes can hold 30 m.

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