Report on Assessment of Test Data,
Sand Box Testing, Cubic Thermoplastic Boxes according to EN 17152-1

Prof. Dr.-Ing. Olaf Selle
Sachverständiger DIBt und EBA
öbuv Sachverständiger
Ingenieurkammer Sachsen

Dr.-Ing. Ricky Selle
öbuv Sachverständiger
und Beratender Ingenieur
Ingenieurkammer Sachsen

Selle Consult GmbH
Shakespearestraße 52
04107 Leipzig

tel +49 (0) 341-30 82 410
fax +49 (0) 341-30 82 411

info@selle-consult.de
www.selle-consult.de

Geschäftsführer:
Prof. Dr.-Ing. Olaf Selle
Dr.-Ing. Ricky Selle

Amtsgericht Leipzig
HRB 17916

Sparkasse Leipzig
IBAN DE54 860 555 92
1100 7674 59
BIC WELADE8LXXX

Project: BD-190115

Client: TEPPFA
Avenue de Cortenbergh 71
7th floor, B-1000
Brussels
Belgium

Author:

Dr. - Ing. Ricky Selle

Leipzig, 30.11.2020

This report includes 15 pages.

Content

1 Reference documents, software and standards

[1] Test Report No. PB 5.2/20-229-1 “Load tests on buried infiltration blocks and tests of short- and long-term strength”, MFPA Leipzig GmbH; 28 October 2020

[2] Simmer, Konrad: Grundbau Teil 1: Bodenmechanik und erdstatische Berechnungen; Stuttgart, 1994 (19. Aufl.)

[3] Deutsche Gesellschaft für Geotechnik e.V. (Hrsg.): Empfehlungen des Arbeitskreises „Baugruben“ EAB; Berlin 2017 (5. Aufl.)

[4] EN 17152-1: Plastics piping systems for non-pressure underground conveyance and storage of non-potable water - Boxes used for infiltration, attenuation and storage systems - Part 1: Specifications for storm water boxes made of PP and PVC-U; 2019-11

[5] EN 1992-1 – Eurocode 2: Design of concrete structures – Part 1-1: General rules and rules for buildings; 2011-01

[6] EN 1997-1 – Eurocode 7: Geotechnical design - Part 1: General rules; 2014-03

2 Introduction

Reservoirs for infiltration, attenuation and storage of stormwater, which are made of cubic thermoplastic boxes according to EN 17152-1 [4] create vertical subsurface walls. These walls are exposed to horizontal soil pressure. Practical experience demonstrates a complex soil interaction of the flexible walls having time dependent deflections and being significantly different from rigid walls as concrete or steel structures. Obviously, structural design based on traditional soil models and soil coefficients, which are derived from rigid walls might lead to overdesigning stormwater boxes or to unrealistic small windows of application for the products.

Since only little scientific knowledge is available on how to calculate horizontal soil pressure on walls of these reservoirs and to account for what is called in the following box-soil interaction, extensive testing of boxes installed in a sand-box as reservoirs was conducted. The test lay-out allowed for measuring soil pressure and deflections under different loads with varying durations at several points of the installation.

The report of the test house MFPA Leipzig displays the test set-up in detail with all sensors and all the data collected [1]. In the following, the data is assessed to generate the key statements which are the basis for a more realistic structural design of the products under horizontal soil pressure in the future.

This report focuses on these most relevant statements for design, where it makes no claim to be a complete assessment.

3 Scope and Concept of Testing

The testing was designed to generate at least key statements on the following 3 issues.

1. Magnitude of horizontal soil pressure, i.e. soil pressure coefficient depending on stiffness and deflection of the walls
2. Changes in horizontal soil pressure under constant vertical loading in relation to time dependent deflections, i.e. on creep of the walls
3. Development of soil pressure and deflection under cyclic loading (traffic)

Furthermore, the lay-out was designed to investigate the influence of the height of the reservoir, i.e. the height of the vertical walls on box-soil interaction.

Modified products according to EN 17152-1 [4] were installed, to test a generic system instead of a specific product. Pillars of the product were taken out in the centre and the cross-section area of the pillars was reduced to decrease stiffness and strength of the boxes in the direction of loading. After modification the boxes had still a stiffness in the upper range of typical values for the horizontal direction to generate rather high horizontal pressure.

Since only one row of boxes on each side of the sand-box was installed, the installation was also in this perspective comparatively stiff and again made to generate rather high horizontal soil pressure and statements being on the safe side. Typical reservoirs with multiple rows of boxes create more flexible vertical walls with more strain capacity.

A total of 6 soil pressure sensors were installed, partly at points of the reservoir with varying stiffness and together with deflection gauges. The gauges were used to verify the readings of the soil pressure sensors if installed at the same spot and to estimate the soil pressure in other areas. Assessing the stress-strain curves of regular short term and long-term tests of boxes according to EN 17152-1 [4] was the instrument to relate stress and deflection readings in the sand box. The focus in this report is on a selection of key sensors.

4 Test Set-Up

A one layer and a two layer installation of boxes on opposite sides of the sand-box was made, to evaluate the possible influence of height of the reservoir on soil interaction (Figure 1 and Figure 2).

The 3 key soil pressure sensors were installed on points with varying stiffness.

1. S3 on the rigid concrete wall, orthogonal to the reservoir walls (Figure 3)
2. S2 in the centre of the vertical plate of the box with pillars taken out, i.e. in a comparatively soft spot with a stiffness of approximately 5 MN/m³ as determined in a short term test [1] (Figure 3 and Figure 4)
3. S5 in-between the 2 layers, i.e. in a comparatively stiff spot of the flexible wall with a stiffness of approximately 20 MN/m³ as determined in a short term test [1] (Figure 4)

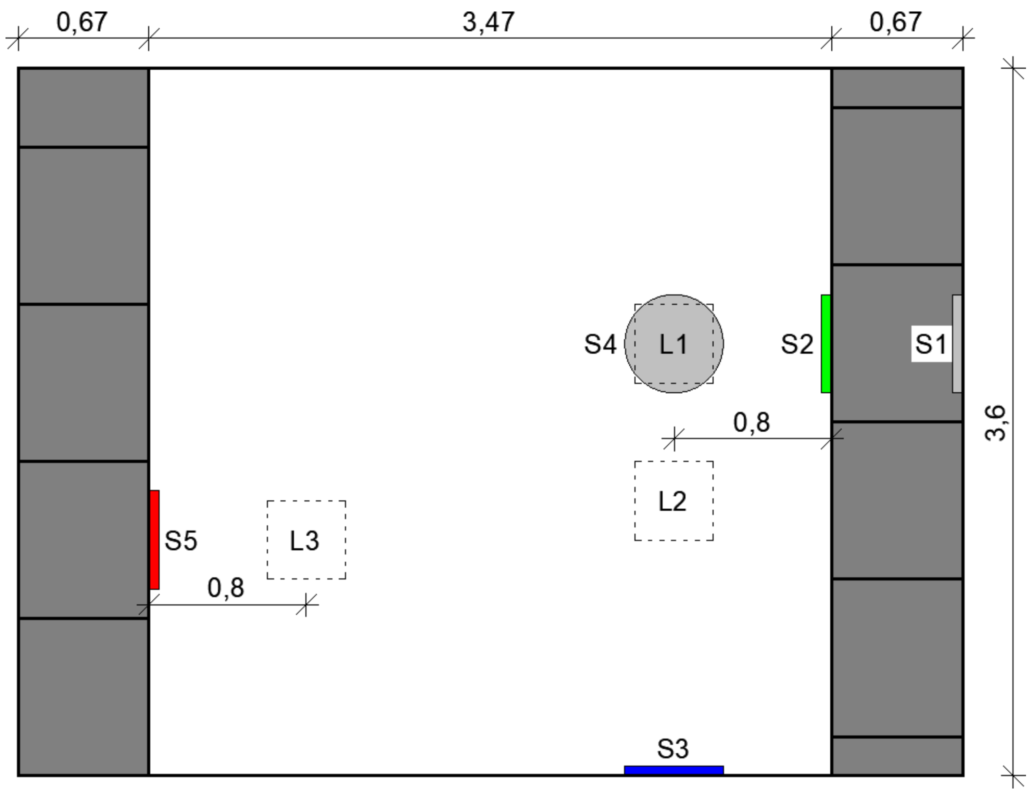


Figure 1 – Top view of the sand-box with soil pressure sensors

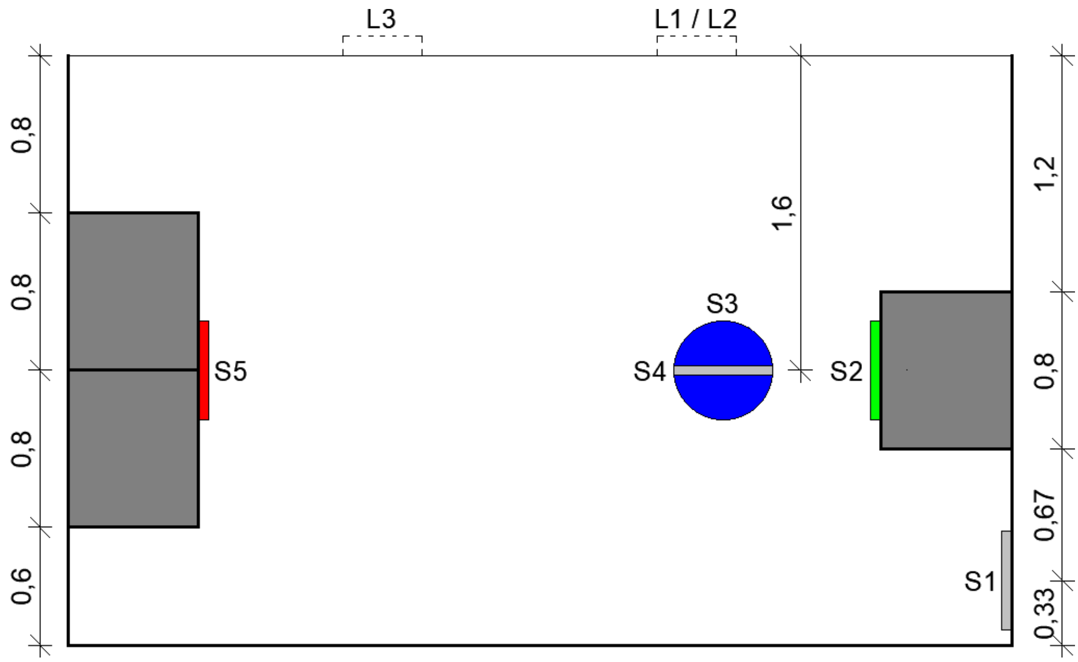


Figure 2 – Section of the sand-box with soil pressure sensors

The colours of the pressure sensors in the drawings of Figure 1 and Figure 2 will be used in the following in charts displaying test data, where the deflection gauges have the respective colours as the sensors.

In the test, after installation and backfilling in principle 3 sets of loading were conducted. Therefore, grouping the test data, i.e. mainly horizontal soil pressure and deflections is reasonable in 4 categories.

1. Installation (backfilling and compacting)
2. 1st set cyclic loading (10 repetitions) in load positions L1, L3 and L2 with a simulated wheel load according to LM 1, Eurocode 2-1 [5] (120 kN on an area of 0.40 m x 0.40 m, minimum load in cycle: 8 kN, load rate of 3 kN/s, i.e. 77 seconds for a single cycle
3. Creep loading in L1 and L3 with a simulated wheel load according to LM 1, Eurocode 2-1 [5] and a duration of 100 hours each; with a resulting vertical soil pressure reading of 31 kPa directly under the load, this can be also regarded as an additional soil cover of approximately 1.50 m
4. 2nd set cyclic loading in L1 and L3, same load regime as 1st set

In the installation a sand with a small and uniform grain size (0/2) and therefore with a comparatively small angle of internal friction was used to create rather high horizontal soil pressure. As the upper layer in the sand-box a gravel-based road construction was installed to allow for the high simulated wheel loads.

Figure 3 – Sand-box with sensors S2 and S3

Figure 4 – Sand-box with sensors S2 and S5

All readings were set to zero after completing installation. Therefore, all readings afterward show only the changes due to the loading scenarios and time dependent behaviour.

5 Scientific approach

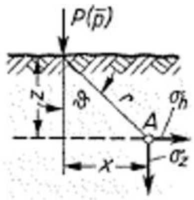
The basis for calculating horizontal soil pressure is always the vertical soil pressure and the soil coefficient. Since the assessment in this report is mainly based on horizontal soil pressure and deflection data from wheel loads, it is essential to calculate the vertical soil pressure in the area of theses sensors.

Vertical soil pressure in this report is calculated according to GRASSHOFF et al. [2] based on tables for a single load, the principle is displayed in Figure 5. All soil coefficients in this document are constantly calculated by dividing the actual reading for horizontal pressure by the theoretical vertical pressure based on GRASSHOFF et al. All pressure readings were checked for consistency with deflection gauges. Readings of deflection gauges were in general the instrument to understand the box-soil interaction and to deduce soil pressure.

The vertical soil pressure was measured with sensor S4 directly under load position L1 at the same depth as of the 3 aforementioned key horizontal soil sensors S2, S3 and S5 (Figure 1 and Figure 2). The reading under the simulated wheel load demonstrates a rather high value (> 4) for the so-called Konzentrations-faktor ν according to FRÖHLICH [2], which is typical for the material used with a comparatively little angle of internal friction.

Punktlast P:

$\sigma_z = i_2 \cdot P/z^2$ nach Taf. **6.34**



6.32 Spannung in der Tiefe z durch Linien oder Punktlast

Tafel **6.34** Beiwerte i_2 für die Spannung σ_z bei Punktlast P

x/z	0	0,1	0,2	0,4	0,6	0,8	1,0	1,2	1,4	1,6	1,8	2,0
i_2	0,477	0,466	0,433	0,330	0,221	0,139	0,0844	0,0513	0,0312	0,0200	0,0129	0,00854

Figure 5 – Principle of calculation vertical soil pressure from point loads according to GRASSHOFF et al. [2]

6 Soil Pressure Coefficient

The principle of horizontal soil pressure being a function of the deflection of the walls is of course well understood (Figure 6) and explained in Eurocode 7 [6]. Nevertheless, the boundary conditions or rigid retaining walls define typical values. Typically, the active soil pressure is regarded as the lower threshold in calculations.

Vertical walls of reservoirs with thermoplastic boxes defected in another magnitude. There is evidence to apply soil coefficients being lower than for active soil pressure, as it will be demonstrated in the following.

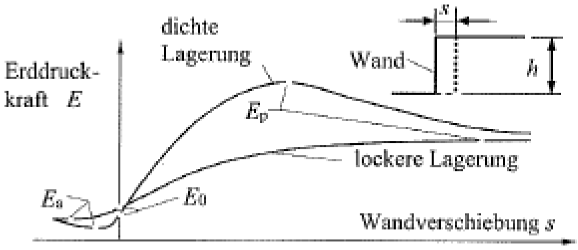


Figure 6 – Horizontal soil pressure E in relation to wall deflection s [2]

Due to time dependent deflections of flexible walls, i.e. creep the soil coefficient is never a constant for reservoirs. This is a challenge for design, since for practical reasons constant coefficients are applied in most geotechnical calculations.

The relevance of using specific soil coefficients and integrating box-soil interaction with time dependent behaviour in design becomes immediately evident by assessing the data of the first cyclic loading.

Soil pressure S2 and related deflections D1 at the rather soft area under cyclic loading in L1, i.e. directly next to S2 and D1, are displayed in Figure 7. The soil coefficient for S2 is about K = 0.05. At the same time, the soil coefficient for S3 greater than 1. Obviously, there is a significant load distribution parallel to the reservoir with the horizontal soil pressure finding the rigid support required. This is typical for box-soil interaction, where the three-dimensional load spread prefers the stiffer direction.

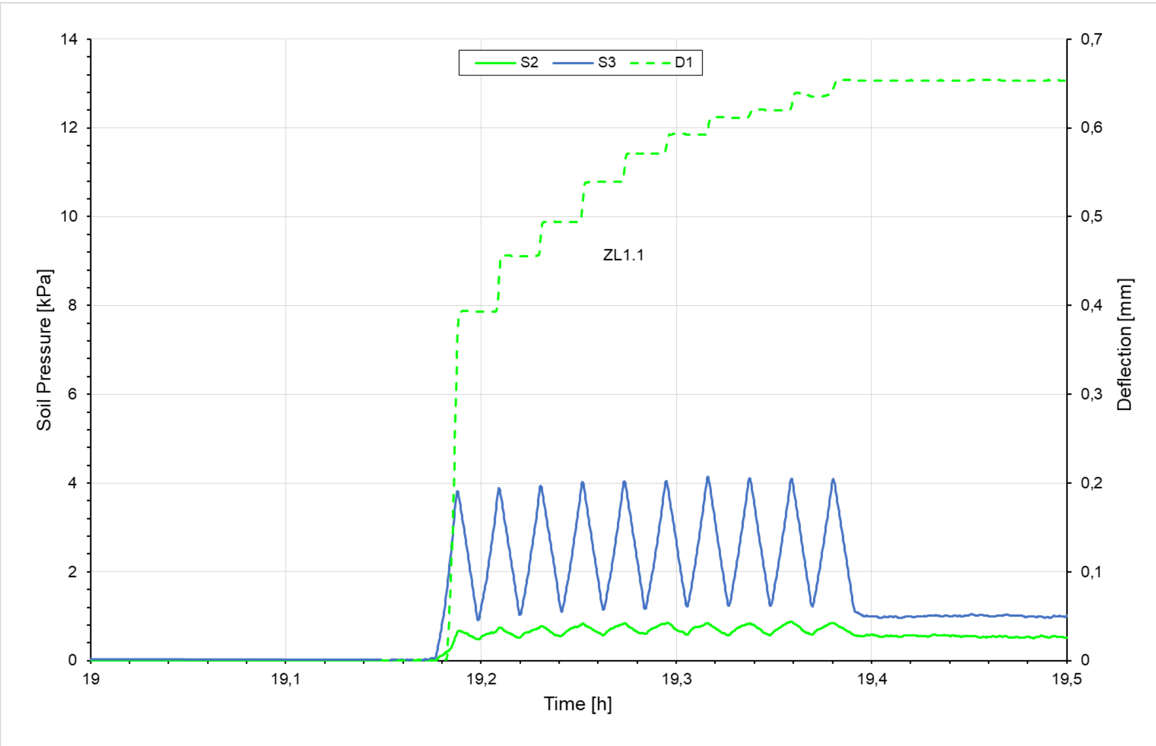


Figure 7 – Stresses and deflections for ZL1.1 (1st set of cyclic loading in L1)

In comparison in Figure 8, the soil pressure S5 and related deflections D4 at the rather rigid area of the flexible wall under cyclic loading in L1, i.e. directly next to S5 and D4, are displayed in Figure 7. The soil coefficient for S5 is approximately K = 0.4, related to the amplitudes of 5 kPa. This is within the range of classical approaches.

The pressure change in the amplitudes of S5 in comparison to the initial increase is partly based on time dependent deflections before this cycle as it will be discussed in Subclause 7, and also on inertia in the soil pressure under cyclic loading. This is well-known as the damping effect of soil in horizontal direction for traffic loads.

Furthermore, according to Figure 8 amplitudes are slightly decreasing with deflections increasing.

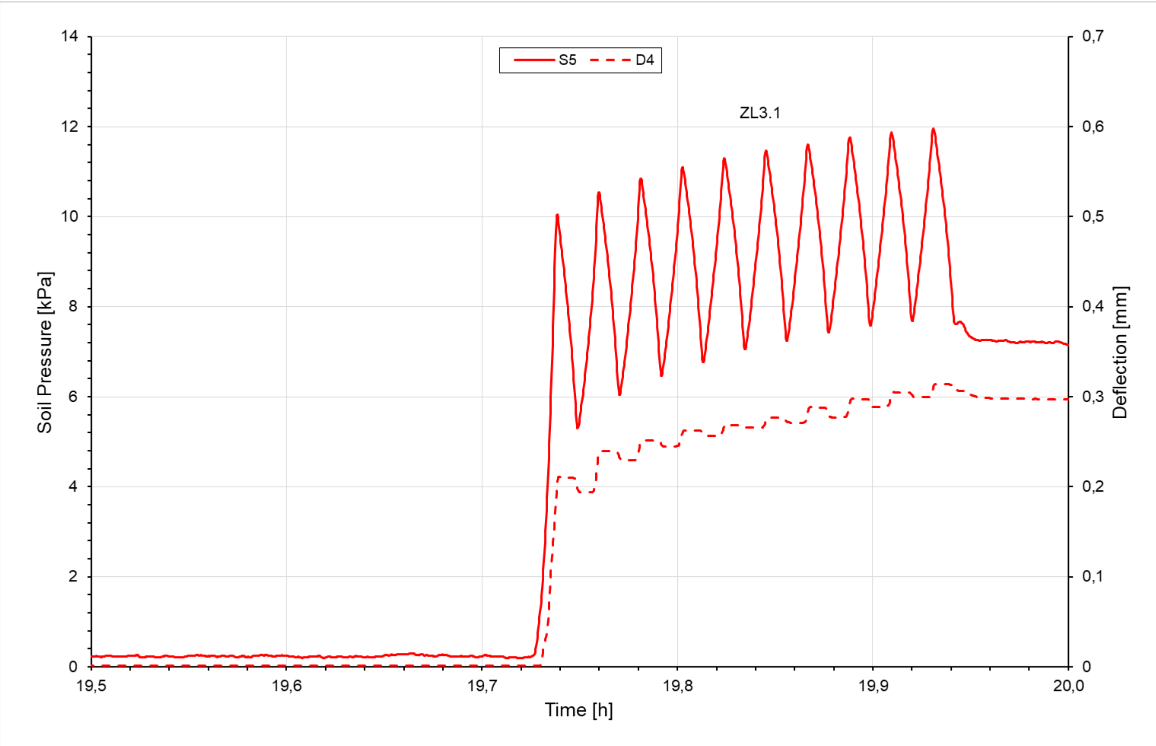


Figure 8 – Stresses and deflections for ZL3.1 (1^{st} set of cyclic loading in L3)

Obviously, there is a huge difference in soil pressure in S2 and S5 under the same loading scenario. The reason for this lies in the history of loading before the two events.

Figure 9 comprises the most relevant pressure and deflection readings for the process of backfilling and final compaction. Taking into account the characteristics of the backfill material, the soil pressure S3 on the rigid wall of 13 kPa gives a very reasonable number for the soil coefficient (0.4), which is close to the soil pressure at rest.

In contrast, there is a significant reduction of soil pressure with time on the flexible walls in S2 and S5. This behaviour will be also discussed in Subclause 7.

Comparing the readings S2 and D1 at one hand and S5 and D4 on the other hand, explains the aforementioned different behaviour under the same loading scenario. While D1 deflects about 5 mm, there is only little deflection for S4, the rigid area of the flexible wall. Against this background, final compaction causes almost no increase of soil pressure S2, while S5 behaves differently.

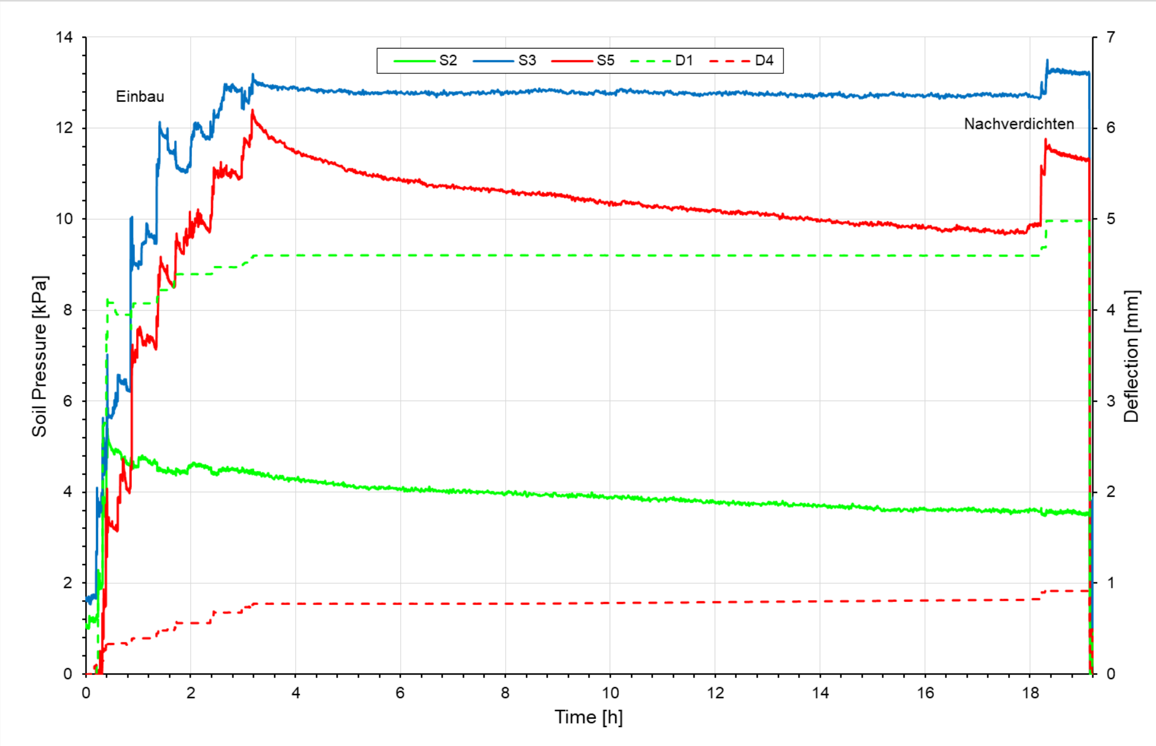


Figure 9 – Backfilling and final compacting

This effect is explained in literature and standards. Eurocode 7 [4] or EAB [3] give for example a threshold of 0.1 % related to wall height as a criterion to decrease the soil coefficient from soil pressure at rest to active soil pressure. Looking at the installation in the sand box, 0.1 % is 0.8 mm for the one layer and 1.6 mm for the two layer installation.

Since the deflections for D1 has already exceeded this threshold after backfilling by far, cyclic loading in L1 has only little impact on Soil pressure. At the same time, the deflections at D4 before cyclic loading are still smaller than the 0.1 % criterion. That is why, the soil coefficient is still in the magnitude of pressure at rest.

It is essential to understand, that for flexible walls not only the stiffness in the direction of horizontal soil pressure determines the soil coefficient, but also the deflections made before. Thus, the soil coefficient changes with time.

This becomes evident by looking at the soil pressure in S5 under the 2nd set of cyclic loading in L3, as displayed in Figure 10. In comparison to Figure 8, the initial increase of pressure is only 5 kPa in the 2nd set of cyclic loading, i.e. only 50 per cent of the increase in the first set. The amplitudes in both figures are similar.

Very different is the remaining deflection after cyclic loading, which can be considered as an effect of post-compaction of the soil under traffic loading. This effect will be discussed in subclause 8.

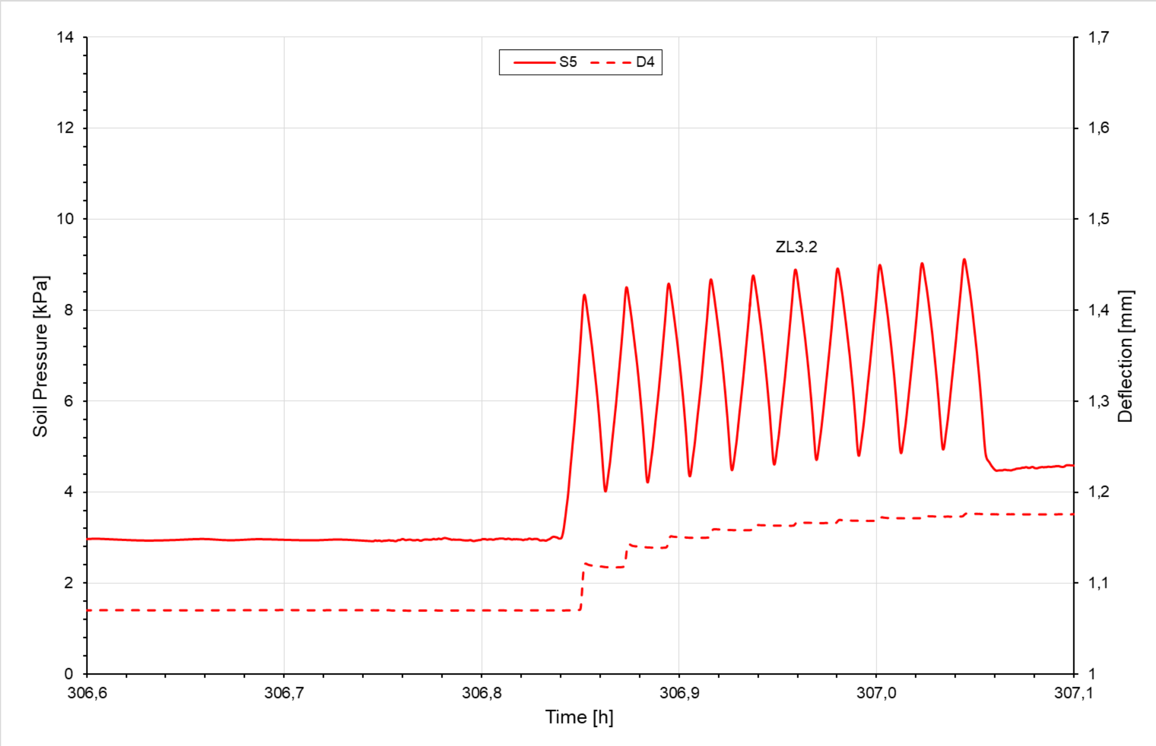


Figure 10 – Stresses and deflections for ZL3.2 (2nd set of cyclic loading in L3)

7 Time dependent changes in soil pressure under constant vertical loading

A time dependent significant decrease of horizontal soil pressure on the flexible walls was already displayed in Figure 9. Another example of this typical phenomenon gives Figure 11. Readings in the time after the 1st set of cyclic loading are displayed. The curves end after the duration of 100 hour creep load in L1 and before the constant load is applied in L3.

After loading L1 and an according increase of soil pressure in S5, the soil pressure drops by almost 6 kPa due to creep and increasing deflection in D4. Including the initial soil pressure after backfilling (11 kPa, Figure 9) und the increase due to the first set of cyclic loading (7 kPa, Figure 8), the decrease in soil pressure is about 30 per cent.

In the time period displayed, there is obviously some noise on all soil pressure cells. According to the manufacturer of the sensors, changes in air pressure cause this noise, since there is only comparatively little pressure on the cells. In order to eliminate this effect, the readings in S3, where no change in soil pressure within the creep period 1 is supposed to occur, are used to flatten the reading for S5. By subtracting the noise of S3 from the S5 readings, a corrected curve (orange) was generated, which shows a typical creep induced shape.

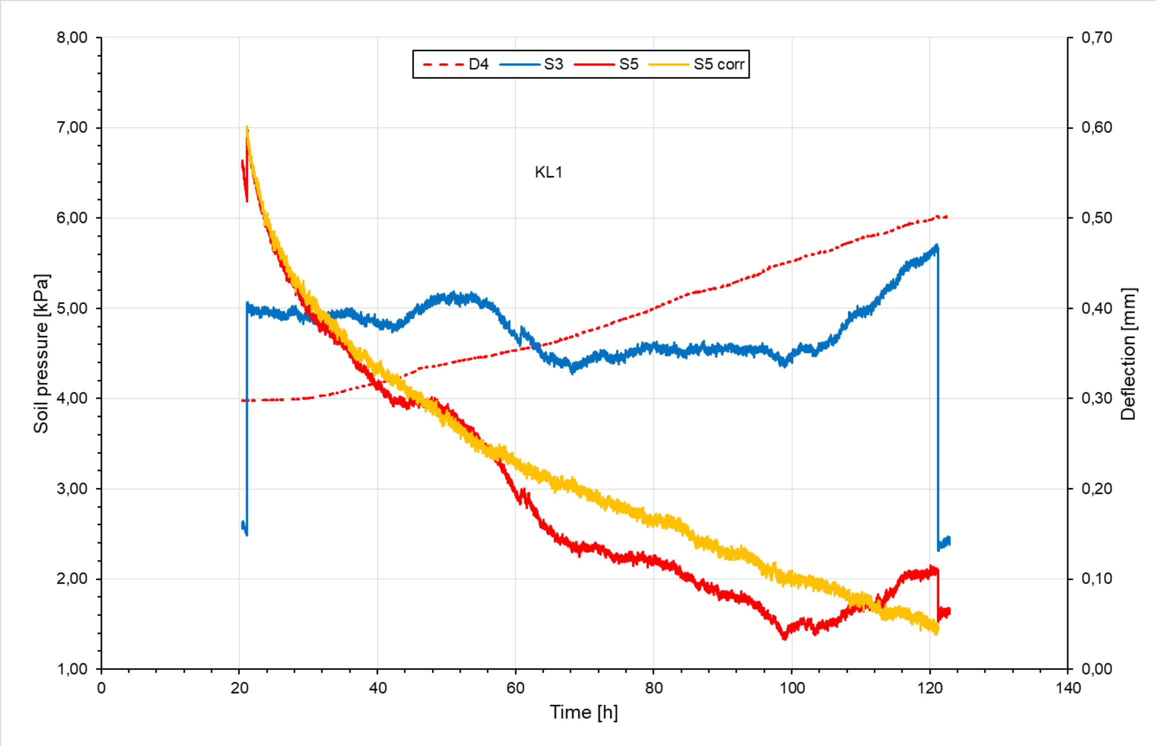


Figure 11 – Decreasing soil pressure at S5 with time

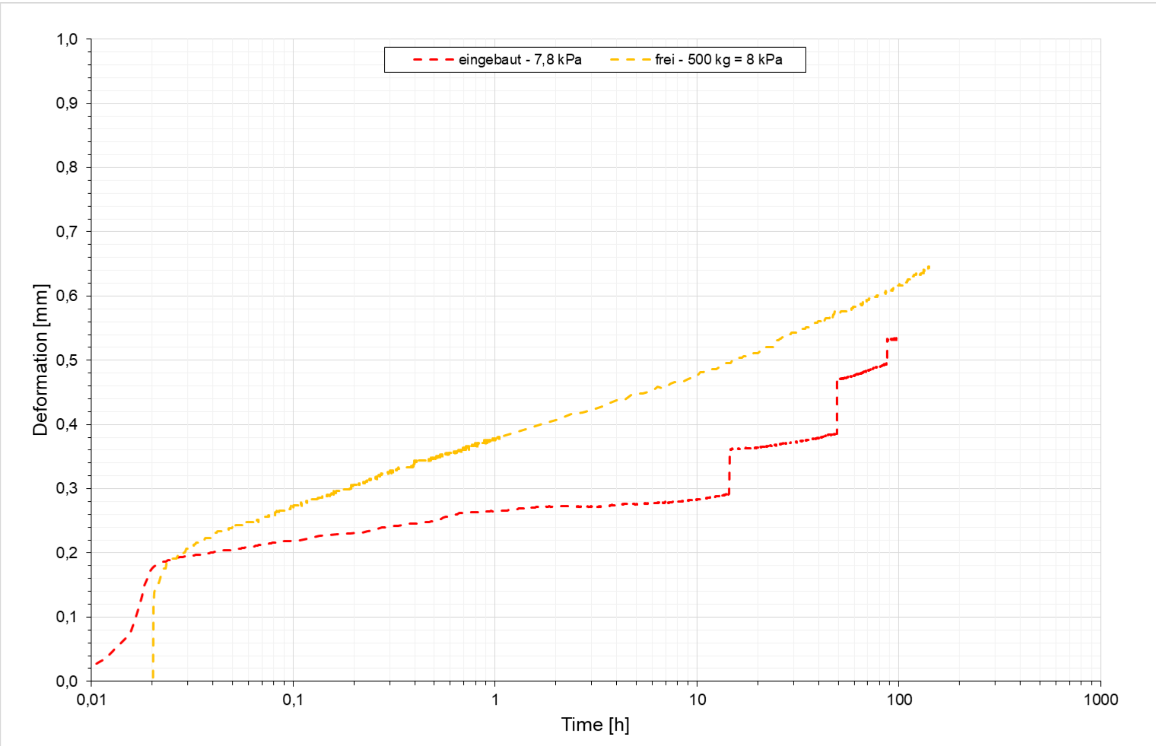


Figure 12 – Comparison of creep in D4 while loading L3 with free standing specimen, both at the same load level

The decrease in soil pressure naturally results in less creep as for constant loading with the same initial load level. Figure 12 shows the comparison of creep deflection D4 after applying the creep load in L3 with a free-standing specimen at the same load level. The steps in the curve for the sand-box readings are caused by the so-called stick-slip phenomenon of the gauge. For the free standing specimen the load was applied with a weight, i.e. instantly, while the damping effect of the soil causes some retardation.

For constant vertical soil pressure, the interaction of deflecting boxes and related changes in soil pressure come eventually to a state of balance, as displayed in Figure 13. Of course, this statement is only based on a rather small period in lifetime. The curves cover a period of more than 60 hours between the cyclic loading in L1 and L3 in the 2nd set. There is a constant vertical soil pressure from cover and apparently no deflection of the boxes. The changes in soil pressure are the aforementioned noise.

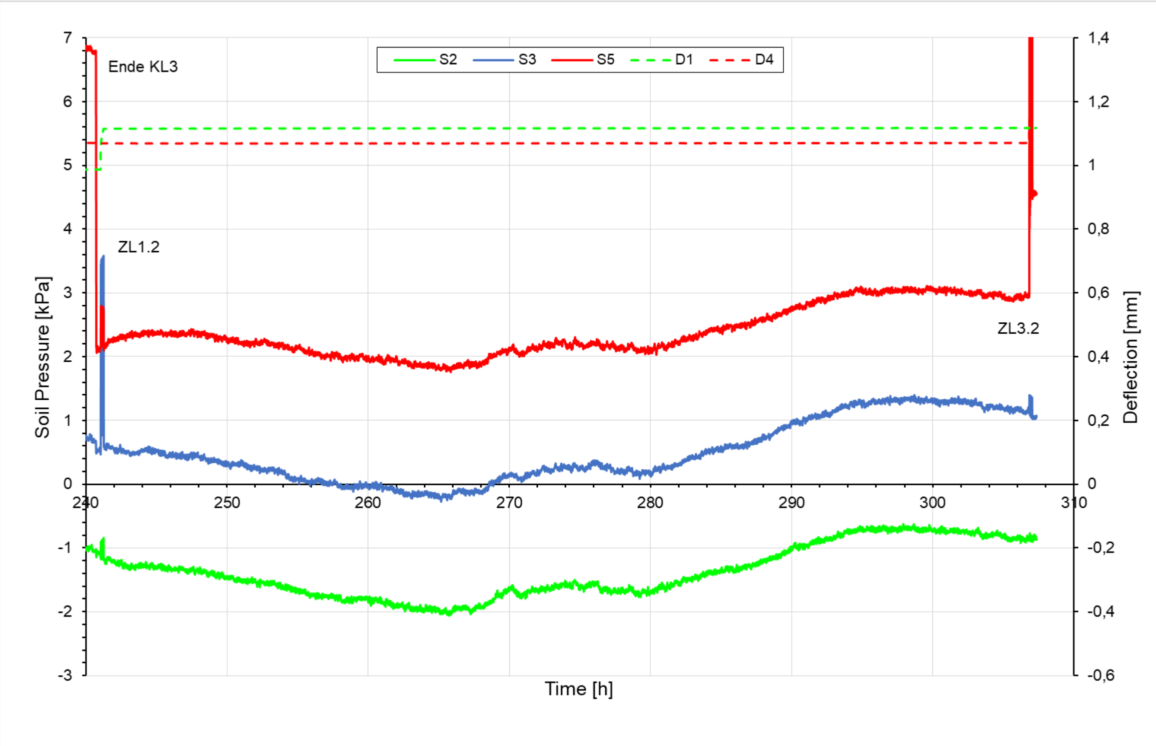


Figure 13 – Time dependent deflection due to soil-box interaction

8 Soil Pressure and Deflections from Traffic Loading

While for horizontal soil pressure resulting from constant vertical loading an eventual stop of creep deflections can be assumed based on the test data, the traffic loading with the effect post-compacting is obviously different. At the same time, both loading scenarios are connected through the cumulated deflections and the effect on decreasing horizontal soil pressure as discussed in Subclause 7.

In comparison of the readings from cyclic loading in L3 of set 1 (Figure 8) and set 2 (Figure 10) at least two phenomena are evident. Horizontal pressure and so-called elastic deflection for one load cycle decreases significantly with cumulated deflection. And so does the soil coefficient. Furthermore, the post-compacting effect also decreases. This becomes obvious by comparing the difference in deflection before and after the set of the 1st cycle (0.3, Figure 8) and the set of the 2nd cycle (0.1, Figure 10).

This is very important for a strain-based design. It is very likely, that again a state of balance will be reached, where traffic loading results only in so-called elastic stresses and deflections.

9 Influence of Height of the System

In assessing the test data, there is no evidence of a significant influence of the height of the reservoir, i.e. the flexible vertical wall on the box-soil interaction. Stresses and deflections for the 2nd set of cyclic loading in L1 are displayed in Figure 14. The readings of D2 give the deflection in the upper part of the box where the pillars are, i.e. a spot with a stiffness as in D4. The deflections due to the 2nd set sum up to 1.2 mm.

In comparison, the deflections in D4 for the 2nd set in L3 are 1.1 mm, i.e. very similar. Apparently, the horizontal soil pressure is not significantly different for the one or the two layer installation.

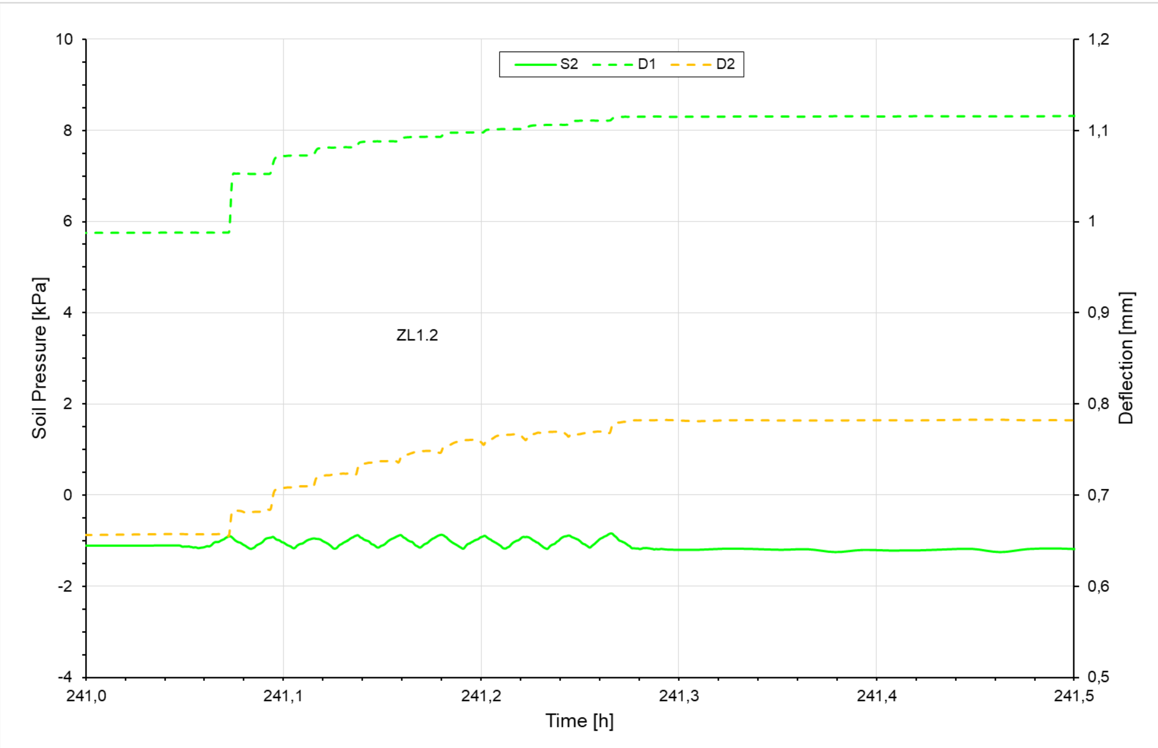


Figure 14 – Stresses and deflections for ZL1.2 (2nd set of cyclic loading in L1)

10 Conclusion

Based on the findings of this report, the following design rules are proposed for horizontal soil pressure from cover and traffic loading, respectively.

1. Since the deflection capacity in horizontal direction, i.e. the strain capacity of the boxes is decisive for structural integrity, a strain-based design should be conducted.
2. Box-soil interaction is different for permanent and transient loading. Therefore design should be made as a combined calculation.
3. Strain analysis should be made for the load bearing elements in horizontal direction.
4. For a maximum horizontal stiffness of the reservoir of 10 MN/m³, based on short term testing (secant modulus at 50 percent of ultimate strain) and number of rows, a soil coefficient of 0.2 should be used in design to calculate the horizontal soil pressure from permanent loading.
5. A factor of 2.0 should be used for calculating the strain at the end of technical life-time (50 a).
6. For the aforementioned maximum horizontal stiffness a soil coefficient of 0.4 should be used in design to calculate the horizontal soil pressure from transient loading.
7. A factor of 1.5 should be used for calculating the strain for a cumulated load duration of 6 month in technical life-time.