ISSN: 2754-4982

Journal of Civil Engineering Research & Technology

SCIENTIFIC Research and Community

Review Article

Open Access

Sandbox Testing for Structural Assessment of Plastic Manholes

Ricky Selle

Selle Consult GmbH Leipzig, Saxony, Germany

ABSTRACT

Structural behavior of flexible plastic manholes is very different from rigid concrete products. Although this is state-of-the-art knowledge, no international or EN standard exists on structural design of these products. Therefore, traditional soil models and soil pressure coefficients are usually applied if calculations for design checks are required. These models are based on rigid wall structures and pipe design methods and do not adequately account for the flexibility and soil interaction of the manholes in the subsurface 3D-space. Recently a working group was established in Germany to develop a design standard for concrete and plastic manholes. In order to calibrate the design equations for the flexible manholes on experimental data and field experience, an extensive in-situ testing of a PP manhole (DN 1000) in a sandbox was conducted. The comparison of deflection readings and calculation result reveals a great difference. Evidently, the assumption of horizontal soil pressure on plastic manholes is wrong. Only soil pressure coefficients of less than 0.1 give realistic results. This is significantly less than the coefficient for active soil pressure, which is widely used today.

Short Summary: The paper presents results from sandbox testing of plastic manholes. It focuses on horizontal deflections resulting from wheel loads at the surface. Explanation is given on why most part of vertical point loads adjacent to flexible manholes is not acting on these products. Theoretical background for this specific behaviour is the load distribution of vertical soil pressure in the subsurface 3D-space. Based on these findings, a range for realistic soil pressure coefficients for actions on plastic manholes is presented.

***Corresponding author**
Ricky Selle, Selle Consult GmbH Leipzig, Saxony, Germany.

Received: December 26, 2023; **Accepted:** December 28, 2023; **Published:** January 10, 2024

Keywords: Structural Design, Plastic Manholes, Verification with Experimental Data

Introduction

Since about 50 years, circular plastic manholes gain constantly market shares in drainage and sewerage networks in competition with traditional concrete products. Manufacturers of plastic manholes point to advantages as a higher media resistance and thus a longer technical service life and installations with less effort due to the significantly lower weight. In the last decades, tremendous practical experience was gained on structural behaviour of plastic manholes.

In order to prove plastic manholes being fit for purpose and a reliable alternative to concrete products, in the 90s a lot of experimental and in-situ data was collected in Europe and North America. A summary of this work is given for example by [1, 2]. These papers in principle in the same fashion look at plastic manholes of different dimensions, installations and loading conditions, describe the relevant load cases for the products and present general statements on structural performance. The 4 main load cases for plastic manholes are:

- vertical loading from wheels
- downdrag forces from adjacent soil settlement
- external water pressure
- radial horizontal soil pressure

The major outcome of this work in terms of standardization were international product standards as EN 13598 and ISO 13272 which define mechanical requirements for plastic manholes to assure fitness for purpose if properly installed [3, 4]. Key requirement of the EN is a long-term test of the manholes with negative pressure (vacuum). The pressure applied depends on allowable external water pressure according to the window of application. In North America ASTM F1759 was launched, a design practice based on the aforementioned paper by Petroff [5].

Today, no international or EN standard exists on structural design of these products. In context with F1759 being not under development but reapproved since the first edition, this fact can be interpreted in two directions. First, proper design of plastic manholes is apparently a complex matter and despite of obvious similarities somehow different from pipe design where standards already exist for a long time. And second and more important: there are no significant technical problems with these products caused by structural performance. If circular plastic manholes being conform with product standard requirements would fail in practice to a relevant extent, the demand for a standardized structural design would of course result a standard on short notice.

This fundamental statement, plastic manholes with appropriate product design, made of durable material and installed according to the manufacturer's manual are being fit for purpose is also the conclusion of the aforementioned paper by Alferink. It states that vertical loading from wheels on a floating cover has almost no impact on the manhole and in most cases downdrag forces are not design relevant due to comparatively little axial stiffness of plastic shafts plus due to stress relaxation. Most relevant for structural design of plastic manholes is to prove resistance against buckling from external water pressure - if existent. For this load case, design can be conducted in principle similar to pipes where sufficient design experience exists. For shafts, this load case is less critical since water pressure is acting rotational symmetrical and creating no bending as in horizontal pipes. Furthermore, the base is creating extra stiffness against buckling. While the 3 load cases discussed above (vertical loading, down drag, buckling) are plausible to most structural engineers, the issue of horizontal soil pressure creates design challenges on a regular basis.

Especially for installations with heavy traffic or railway loads, the non-existence of an international standard is a problem. Typically, engineers are confronted with existing design approaches based on flexible pipes or on rigid concrete manholes, where standards both exist. This creates artificial problems for manholes, particularly of greater dimensions or of less but appropriate ring stiffness. These approaches (and also ASTM F1759 equations) result in deformations and stresses, which are in contrast to practical experience.

Another design challenge is to account for the loads from uneven soil compaction around the perimeter of the shaft. This is a relevant load case for concrete manholes. Figures of uneven horizontal soil pressure can be drawn from referring standards. For example, DIN 4034 requires a design check for a ratio of 1:2 (Figure 1) [6]. At the same time, the assumption of significant uneven soil pressure is just false for plastic manholes due to flexibility, soil ring interaction and stress relaxation. A design standard giving this statement of course would be beneficial.

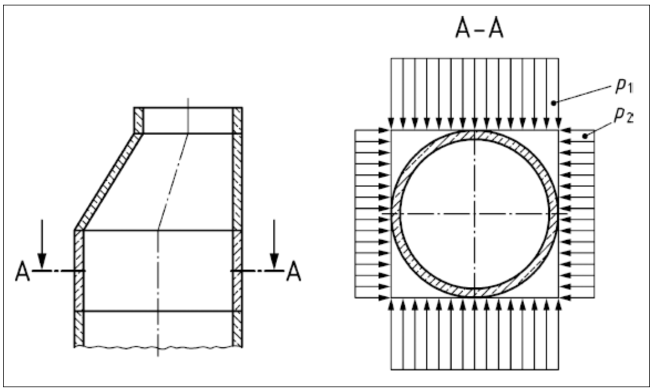

Figure 1: Uneven horizontal soil pressure on concrete manholes according to DIN 4034

Against this background, recently a working group was established in Germany to develop a new design standard for plastic manholes. Concrete products will be also covered, which is rather challenging in one standard. Regarding the plastic products, this standard will have impact on standardization in EN or ISO. In order to calibrate the design equations on experimental data and field experience, on behalf of TEPPFA an extensive in-situ testing of a manhole (REHAU AWASCHACHT PP DN 1000) in a sandbox was conducted by the German test house MFPA Leipzig [7]. Deflections were measured of the manhole from loads in different positions close to the manhole. The focus of testing was horizontal soil pressure from heavy traffic wheels with varying durations. The writer is a member of the working group und the consulting engineer for the testing.

Discussion

The plastic manhole DN 1000 with a shaft consisting of 3 rings (lowest one with invert and base) and cone, a height of 3,00 m and ring stiffness of 4 kPa was installed in a non-cohesive sand filling (Figure 2). Sand with a grain size of maximum 2 mm was chosen because of its relatively poor direct vertical load transfer under point loads. A well graded soil would transfer loads within a smaller cone- like volume into the ground and create less interaction with the manhole. Since the maximum wheel load according to Eurocodes was applied in the testing, a well graded soil layer with angular stone was placed over the filling to simulate a road construction. Again, a parameter being on the safe side was chosen for the testing. In comparison, a concrete or asphalt layer for the road construction would have led to a better load spread and less horizontal soil pressure.

Figure 2: Testing layout, instruments in the manhole

The focus in testing and data collection was put on horizonal deflections of the cone at the lower edge and the upper ring directly under the cone (Figure 3). These measurements reflect in the most consistent way the actions of horizontal soil pressure from wheel loads in different positions. The measurements were conducted with rope tension gauges (Figure 2). There were more sensors placed in the manhole, for example to measure the vertical deflection of the cone with the load put in the critical positions for the cone, i.e., at the edge of the cover and directly over the saddle of the cone. These readings were consistent with the aforementioned field data of the 90s indicating no critical scenario and will be discussed elsewhere.

The critical load position for maximum horizontal deflection of the shaft is next to the cover on the "ladder side" of the manhole (Figure 3). The maximum wheel load for heavy traffic (Load Model 1,120 kN on a square area with 400 mm side length) was applied via a hydraulic load cell as short-term load and as a creep load for 100 hours simulating a parking vehicle.

Parallel to sandbox testing, ring stiffness was determined for the cone and the shaft and creep deflection accordingly. With this data, deflections can be related analytically to actions, i.e., to horizontal soil pressure.

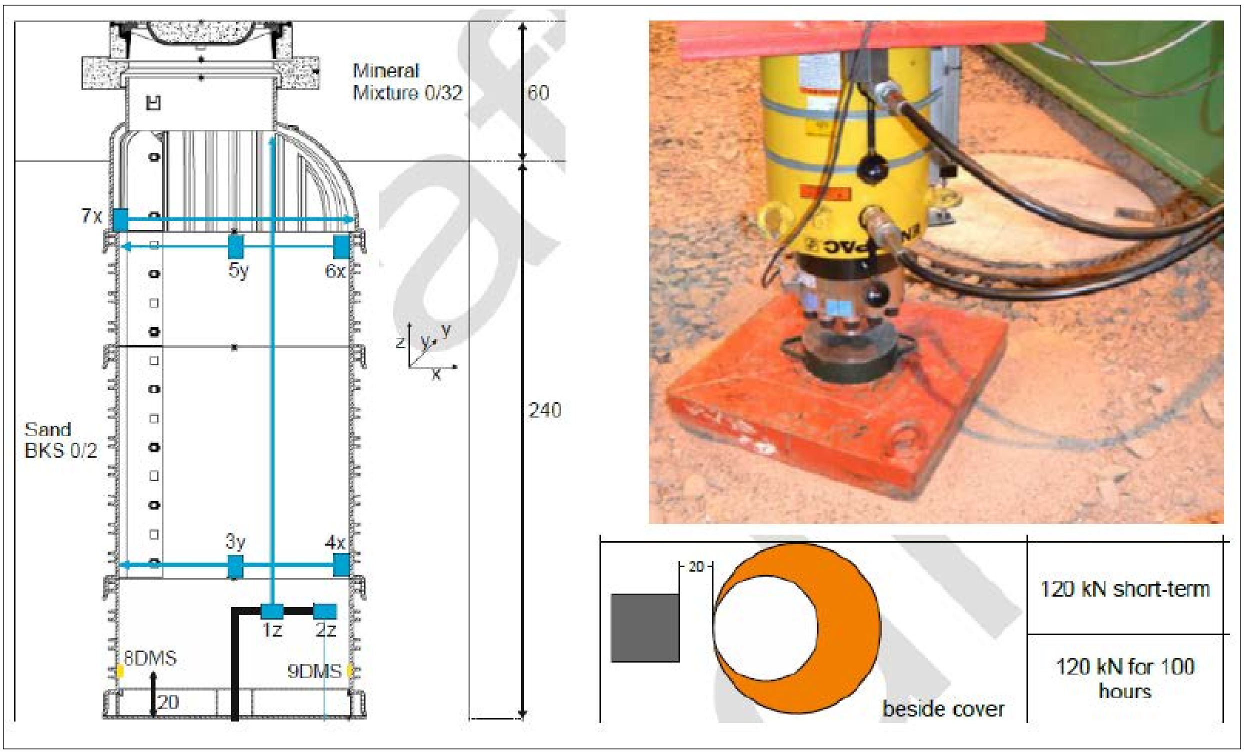

Figure 3: Instrumentation layout, critical load position

The deflections of the cone and shaft are displayed in Figure 4 (short-term) and Figure 5 (long- term). The data is consistent with findings of the aforementioned studies conducted in the 90s. The maximum deflection for short-term loading is on the lower edge of the cone with the least ring stiffness (lower than 4 kPa). The positive (ovalisation inwards) and negative (ovalisation outwards) readings at the upper edge of the ring are smaller. That is also because the lower part of the ring provides extra stiffness. It sees less pressure since horizontal soil pressure from point loads at the surface decreases with depth. Against the high loads and the critical load position, the general magnitude of readings is little with the maximum at 1.2 mm.

In comparison to short-term loading, the deflections for long-term loading are smaller including creep (negligible after 1 hour). Creep deflections are much less than material characteristics would suggest, due to the effect of decreasing soil pressure on deflecting rings and eventually finding an equilibrium. A typical PP material has a 100 hours creep modulus of less than 50 per cent of short-term modulus. If deflections would depend solely on material creep, this would result in an increased deflection after 100 hours being 200 per cent of initial deflection. In fact, deflections of cone and shaft increase to less than 150 per cent. Obviously, loading resulted in some settlement of the interactive manhole-soil-system already after about 1 hour.

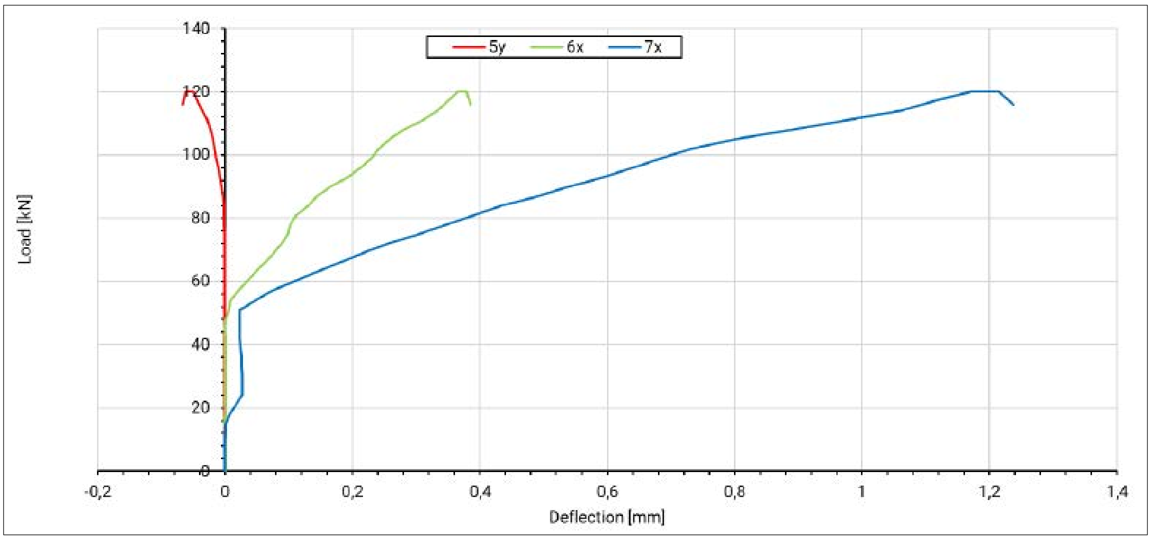

Figure 4: Deflection readings from short-term loading (120 kN)

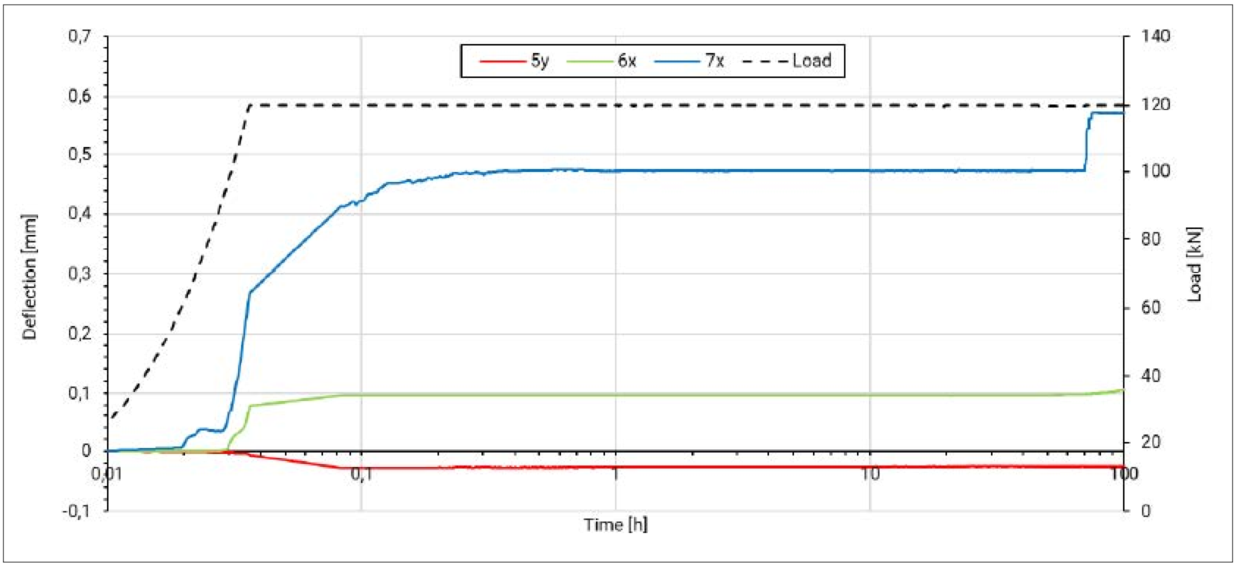

Figure 5: Deflection readings long-term loading (120 kN, 100 hours), data missing 0,03 – 0,08 hours

In order to simulate a passing live load on the pre-deformed structure, after long-term loading a cyclic loading with a 10 times repetition of 120 kN in the critical position was conducted. No significant increase of deflection in the manhole was observed. It is expected, that deflections from parking vehicles are the worst-case scenario and after unloading are to some extent regressing with time. The data indicates that deflections from cyclic loading, i.e. passing live loads, do not exceed deflections from parking vehicles and that these deflections do not add up.

Another plastic manhole DN 1000 with a higher ring stiffness (8 kPa) was also installed in the sandbox to back up the findings of the testing (Figure 2). Deflection data of this manhole shows smaller values and confirms the results of the SN 4 manhole.

Testing was accompanied by calculating deflections by state-of-the-art approaches. These approaches are all based on pipes. This is per se not the problem since the analytical solutions for ring deflections under loads are undoubtedly correct. Nevertheless, although the measurements of the shaft ring display short-term deflections of less than 0.5 mm, calculations propose deflections of 7 mm. The magnitude of difference is at least a factor of 10. The deviation from measurements is even greater for long-term calculations.

Conclusions

Evidently, the assumption of actions on plastic manholes in terms of soil pressure is wrong. Wheel loads result in much smaller horizontal soil pressure than calculated with classical soil pressure coefficients, as for example in F1759, Eq. 2. These coefficients were established for calculating soil pressure on walls, i.e., for a load distribution in a two-dimensional plane. Calculating manholes in analogy to pipes follows the same idea. Vertical stresses in a 2D-plane have to go into the ground, for flexible pipes with arching to a high extent through the surrounding soil. But for manholes, horizontal stresses distribute in a 3D-space. Therefore, the classical soil pressure coefficient approach and the pipe calculation method is not applicable. A plastic manhole is the soft spot in the 3D-space. It does not attract horizontal stresses. Load distribution in general prefers short distances and rather stiff abutments. In comparison to the plastic manhole, this is the surrounding soil.

In consequence, a paradigm shift is required in structural design of plastic manholes. Soil pressure coefficients for actions on manholes should be based mostly on ring stiffness and only to a smaller extent on soil properties. Based on experimental and field data, only coefficients of less than 0.1 give realistic results and provide results in structural design the approved windows of applications. This is significantly less than the coefficient for active soil pressure, which is widely used today.

In further consequence, a requirement for tests with loading plastic manholes in horizontal direction which prove minimum stiffness and flattening capacity could eliminate the need for a detailed structural evaluation.

References

1. Alferink F (2001) Performance of Buried Plastics Manholes, Proceedings of Plastic Pipes XI.
2. Petroff L J (1994) Design Methodology for HDP Manholes, Buried Plastic Pipe Technology: 2nd Volume, ASTM STP 1222.
3. EN 13598 (2020) part 1 and 2 Specifications for manholes and inspection chambers (Plastics piping systems for non-pressure underground drainage and sewerage).
4. ISO 13272 (2011) Specifications for manholes and inspection chambers in traffic areas and underground installations (Plastics piping systems for non-pressure underground drainage and sewerage).
5. ASTM F1759-97 (2018) Standard Practice for Design of High-Density Polyethylene (HDPE) Manholes for Subsurface Applications.
6. DIN 4034 (2020) Prefabricated concrete manholes, unreinforced, steel fibre and reinforced.
7. MFPA Leipzig (2022) Report: Sand box testing on Rehau sewage manholes (PP DN 1000) for determining horizontal deflections under traffic loads.