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Continuous Cross-Section Measurement in Ovoid Pipes - Practical Experience in Dortmund

A construction project of the Dortmund Sewage Department covers among other things the modernisation of brick-built sewers with an ovoid cross-section which have been in uninterrupted service for a period between 97 and 135 years. To ensure the maximum possible execution reliability of the planned internal rehabilitation measures, the actual cross-section was to be determined over the total length of all sewer sections. For this purpose, a continuous, laser-supported cross-section measurement was performed with the pan and rotate camera IBAK ORPHEUS 2 in a single operation together with the optical inspection. The results of the measurements serve as a basis for rehabilitation planning and the choice and dimensioning of liners for the consulting engineering company VOGEL Ingenieure GmbH which was commissioned with the planning.

1. Scope of the Project

The sewage department of the City of Dortmund with a population of nearly 600,000 operates a highly complex sewer system with a length of 1,996 km. Besides the sewers, infiltration and retention basins with a surface area of 33 hectares are maintained within the municipal area. The municipal undertaking has commissioned VOGEL Ingenieure GmbH to plan the rehabilitation of the combined wastewater sewers that are in need of repair. The declared aim of the project is to preserve and modernise the sewers built during the period from 1882 to 1920. The objects for rehabilitation include among other things 24 brick-built sewer sections of ovoid cross-section with internal sizes of 600/900, 700/1050 and 900/1350 and a total length of over 1230 metres. The City of Dortmund Sewage Department attaches great importance to comprehensive expert planning as this contributes decisively to the sucess of any rehabilitation measures. VOGEL Ingenieure GmbH recommended that the actual internal sizes should be determined in the course of the optical inspection which had to be performed in any case.

2. Planning and Preparation

The construction method used at that time had advantages in hydraulic terms; to some extent the sewers had a curved layout. The lateral inflows of some of even the bigger collector sewers are connected to the trunk sewer without direct accessibility, e. g. in the form of inspection chambers. The sewer installations concerned are predominantly located in highly frequented traffic areas, in the pedestrian precinct and the main shopping thoroughfares, placing increased requirements on the organisation of the job site workflow. To ensure traffic safety, various traffic-related permits had to be obtained in coordination with the local traffic authority. In order to acquire information of a sufficiently high quality, the sewer sections to be inspected were taken out of service and the outflows were diverted. The sections were cleaned beforehand by high-pressure jetting. Isolated results of TV inspections performed in the years 2006 to 2014, digital site plans and the manhole measurement data were available as preliminary data. To perform the optical inspection of the sewer sections and manholes and to determine their internal sizes, various accompanying services had to be performed. These were carried out by different service contractors. VOGEL Ingenieure GmbH undertook the complex overall coordination to ensure the smooth implementation of the data capture and to provide a coordinated time schedule for all steps in the workflow.

3. Limitations of the Procedures Used Hitherto

To supplement the assets data, on-site measurements at manholes has become established as a standard procedure. In man-sized sewers, hitherto, additional pointwise measurements were made at certain pipe locations. However, the circumference of brick-built sewers can change within a few centimetres. Varying internal dimensions over the run of a section are not identified by pointwise measurements at the ends of the pipes and are therefore not taken into consideration during further procedures. At best, allowance is made for erratic changes in the internal size over the run of a sewer section when the liners are dimensioned. These changes of cross-section can usually be identified during the optical inspection (see. fig. 5). However, changes of cross-section can also be gradual, so that they are not visible to the naked eye (see. fig. 6). As exact as possible information on the actual internal size is however relevant for dimensioning the liners to fulfil the stipulation of achieving a technical life span of at least 50 years.

4. Continuous Cross-Section Measurement

The optical inspection was performed with the IBAK ORPHEUS 2 which, with the lasers integrated into the fully rotational camera head, permits the measurement of the cross-section over the entire length of sewer sections in ovoid sewers. The laser scan was performed directly after the optical inspection when the camera was on its way back from the target manhole to the start manhole. The massive fractures in the invert and the bends in the section required an extremely robust camera carriage. The powerful IBAK T 86 camera tractor travelled back at a constant speed of approximately 5 to 7 cm/sec. until the length counter showed a reading of 0.0. The inspector started recording the continuous cross-section analysis via the IKAS evolution software. As the lasers are integrated into the inspection camera, the laser measuring system did not have to be mounted at the front of the camera with a holder. So the inspector does not have to spend any additional time and effort on installation work and the scanning process of the cross-section measurement fits optimally into the working procedures of the TV inspection.

Fig.1:
In Dortmund, the continuous cross-section measurement over the entire length of the sewer sections with ovoid cross-section was performed with the ORPHEUS 2. The continuously rotating measuring head of the inspection camera enabled the actual inside circumferences to be determined in a single operation together with the inspection.

5. How It Functions

If the operating mode is switched over from inspection mode to laser scan mode, the lighting switches off automatically, the laser measuring system switches on automatically and the camera is aimed automatically at the pipe wall. On the basis of the two laser points, the system determines the distance between the camera and the pipe wall. The entire cross-section of the section is finally captured as the system reverses out of the sewer while the camera is simultaneously rotating. A spiral of laser measuring points is generated. If the reversing speed is higher, bigger, elongated spirals are created because less laser measurements are captured. The slower the camera reverses, the narrower the spirals are that are formed because the laser measurements are captured at closer intervals. As the centre of the pipe is calculated from the measured values, the centre axis of the camera head need not necessarily coincide with the centre axis of the pipe.

6. Analysis with the Software

The laser points captured in this way were analysed with the IKAS evolution software and evaluated by the planning engineers from VOGEL Ingenieure GmbH. The user can choose between performing the analysis at the workstation of the TV system or on the PC in the office. The choice of the suitable procedure depends decisively on the individual case in question. As the intended use of the measured data ranges from the acceptance of construction work or warranty inspections to the selection and dimensioning of liners, there are different requirements regarding the proper post-processing of the measuring results. Within the framework of the inspection described here, data processing was performed by experts from VOGEL Ingenieure GmbH using the office version of the pipe cross-section analysis software.

6.1. *Plausibility Check of the Measured Data*

The consulting engineering company entered the desired value for each sewer section with ovoid cross-section in the settings of the pipe cross-section analysis software. In the viewing options, the desired value curve can be overlaid to compare the displayed measuring points with the ideal dimensions. This option is useful for the plausibility check (see fig. 2).
If you click on a position in the cross-section of the pipe, the software goes to the corresponding position in the video. At the same time, the video image can be adjusted so as to provide an optimum view of the measuring point. Thus, the results of the measurements could be directly checked for plausibility by means of the video recording of the optical inspection. In this way, the consulting engineering company was able to correlate conspicuous measured values to actual features such as residual water in the pipe invert, solidified deposits, entrances to connection pipes, missing wall sections or projecting obstacles.

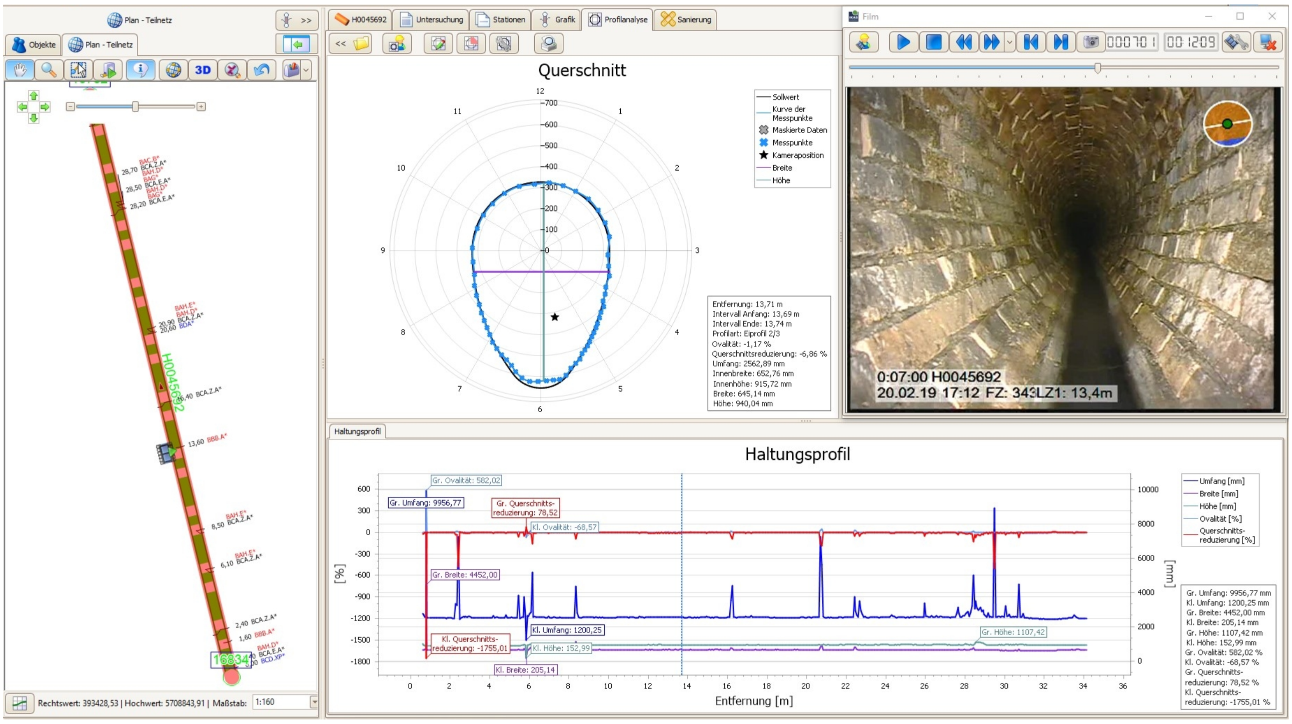

Fig 2:
View from the IKAS evolution software

Left:	Network plan with the current camera position marked (video symbol) in the sewer section currently being processed (highlighted in red)
Top centre:	Cross-section of the pipe as an extract from the measured spiral (blue line) with entered desired value curve (black line)
Top right:	Video image directly before the measuring point
Bottom right:	Graphic of the complete section (blue line = ovality, red line = reduction of cross-section; the vertical blue line shows the position in the cross-section)

6.2. *Post-Processing of the Measured Data*

Parts of the pipe whose effects on the calculation of the inside circumference are undesirable can be marked with maskings and eliminated. These can be e.g. connection pipes or standing water. The measured values captured in these parts of the pipe are not relevant for determining the ovoid cross-section as such. These also include deposits which are irrelevant for any planned rehabilitation measures because they are removed beforehand. This is why the software provides the possibility of cleansing the measured values. The maskings should be performed by someone with expert knowledge of rehabilitation requirements. The consulting engineering company defined angular zones over one or more layers in each part of the sections in question where the measured values were to be excluded from the calculation of the inside circumference (see fig. 3). Within the maskings, the actual values were replaced by ideal values. The ideal values were calculated taking into consideration the captured measured values and on the basis of an ideal cross-section.

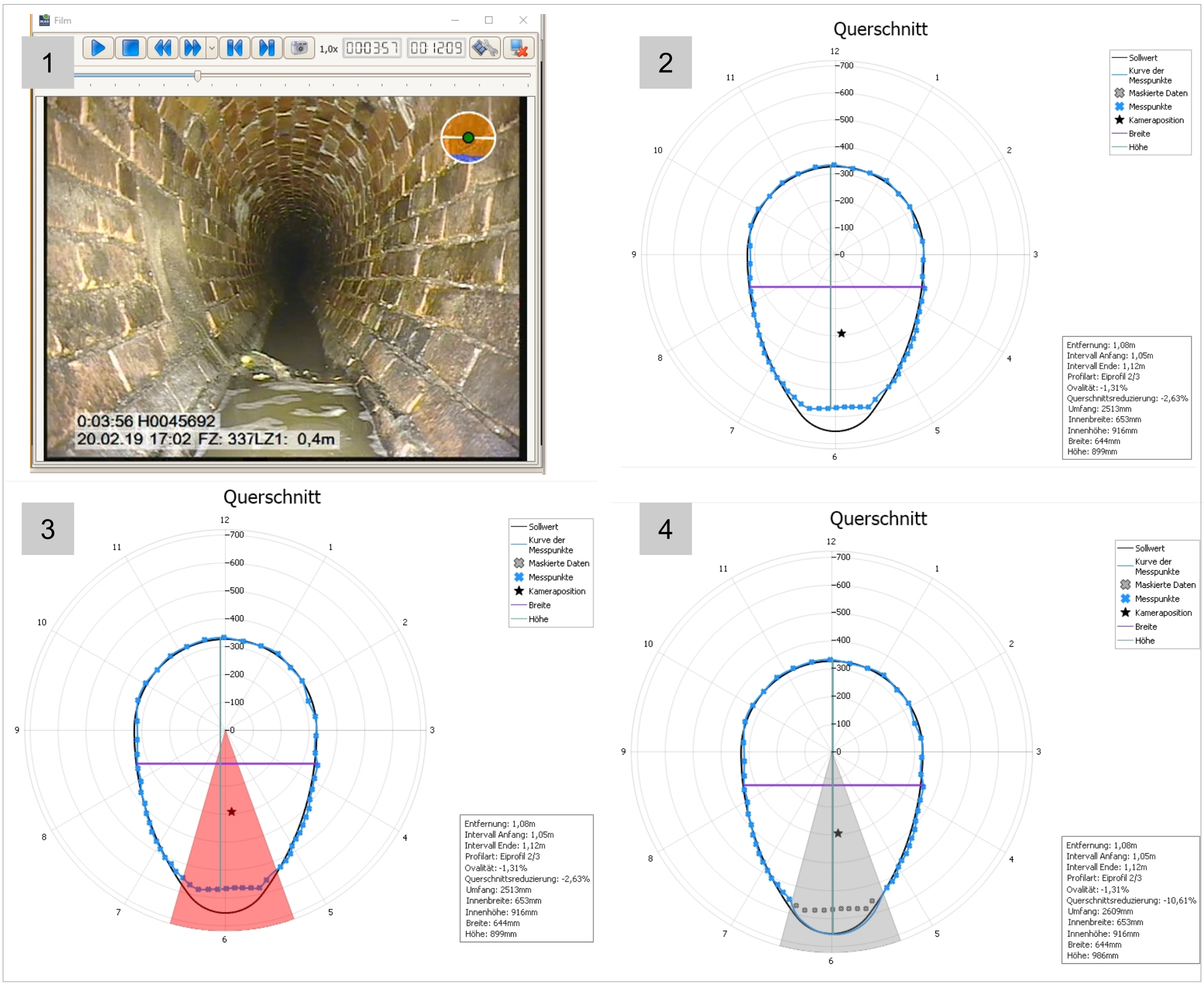

Fig 3:

1. Video image directly before the measuring point with visible sewage in the invert
2. Cross-section of the pipe as an extract from the measured spiral (blue line)
   → black line = ideal cross-section
   → A measured circumference of 2513mm is indicated
3. Selection of the masking area (red angular zone) to prevent these
   measuring points from affecting the calculation of the circumference
4. Within the masking, the actual measured values are replaced by ideal desired values
   → A corrected circumference of 2609 mm is indicated

This expert post-processing has a decisive influence on the significance of the measured data for dimensioning the liner. The correction of the measuring points in figure 3 can be seen as an example of this. Before post-processing, a measured circumference of 2513 mm was indicated at this position. Some measuring points were affected by the standing water in the invert. These measuring points were replaced by ideal values for this pipe size. The corrected circumference at this position is now 2609 mm and is thus 3.8 % bigger than actually measured. Expert post-processing ensured that irrelevant measuring points have no effect on the planning of rehabilitation measures.

6.3. *Results from Dortmund*

Table 1 provides a summary of the results of the analysis. The analysis of the measured data showed that all the measured pipes under review here were greater in circumference and height than was indicated in the asset plans. The maximum variation in the circumference within individual sections (between the maximum and minimum measurement) was more than 7 % in 7 out of 24 cases (see the values highlighted in red in tab. 1). In section 10, the maximum measured circumference is 12.5 % bigger than the minimum circumference measured in this section. Thus, a liner for this section, chosen on the basis of the minimum circumference, would have to stretch by 12.5% in order to fit the maximum circumference.

In section 11, the minimum measured circumference is 17.02 % bigger than the ideal circumference for the internal size of 600/900 stated in the assets data. This measured deviation induced the planning engineers from VOGEL Ingenieure GmbH to correct the internal size of this section to 700/1050. In section 20 an intermediate size was ascertained: the minimum measured circumference is 13.11 % bigger than the ideal circumference. Thus, section 20 is bigger than 600/900 but smaller than 700/1050 (see the values shown in red in tab. 1).

But even with measurements which deviate from those stated in the assets data but which do not seem significant at first sight, expert evaluation of the data is advisable. Here a sample calculation from VOGEL Ingenieure GmbH with reference to section 1 of table 1: according to the assets data, it has an internal size of 600/900. This means that an ideal circumference of $U_{600/900,\ desired}$ or 2.38 m is presumed. On the assumption that manufactured liners can have a negative tolerance of 3%, this results in a circumference of $U_{600/900,\ -3\%}$ or 2.31 m. The maximum measured circumference of this section is $U_{max,\ actual}$ or 2.53 m. Thus, a pipe liner ordered for an internal size of 600/900 and manufactured with a negative tolerance of 3% would have to be able to stretch by up to 9.5% in order to fit the maximum circumference of this section. Particular attention must be paid to the stretch capability when a suitable liner is selected. A stretch capability of 9.5% is beyond the limits of some of the liner systems available on the market.[1]

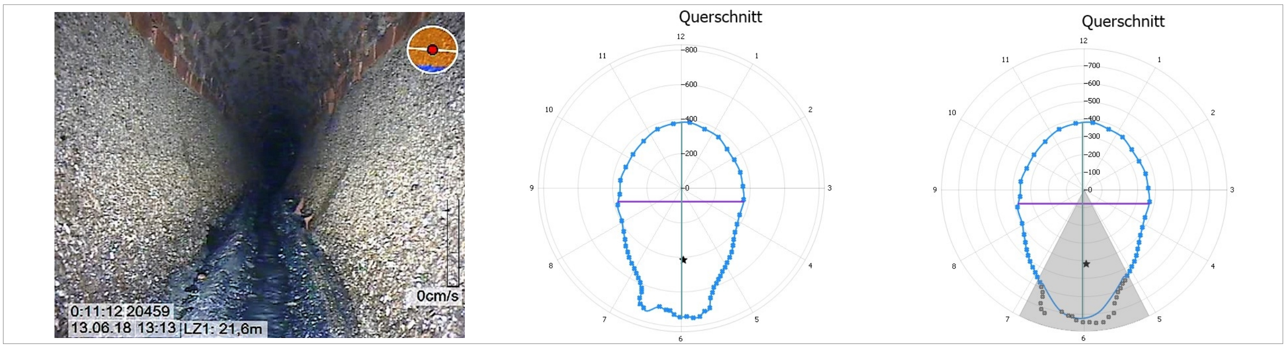

Fig. 4:
Left	Video image directly before the measuring point
Centre:	Cross-section of the pipe as an extract from the measured spiral with fractures in the invert
Right:	Masking of the zone which will be repaired with PCC mortar before installation of the liner: the measured values have been replaced by desired values in this zone.

1 For further information see the professional article by Markus Vogel (2018): 'Schlauchlining – bewährt, aber nicht trivial!' https://www.vogel-ingenieure.de/assets/Uploads/module/downloads/bbr-0708-2018-20-31-Vogel.pdf

The laser scan of the sewer sections enabled data and therefore insight beyond the scope of a purely optical inspection to be gained or the inspection results to be corrected in certain cases. For example, in the video image from the optical inspection in fig. 4, you get the impression that the concrete surface is curved inwards. This could lead to the conclusion that the circumference is smaller in this zone. This supposition that was based on image data from the optical inspection was proved wrong by the measurement of the cross-section (Fig. 4 cross-sections, centre and right).

Haltung	Bestandsdaten (BD)					Messergebnisse Profilanalyse				
	Baujahr	Haltungs-länge [m]	**DN Breite [mm]**	**DN Höhe [mm]**	**Idealer Umfang [mm]**	**U, min [mm]**	Differenz U ideal zu U min	**U, max [mm]**	Differenz U ideal zu U max	**Differenz U max zu U min**
1	1920	46,7	600	900	2379	2432	2,23 %	2528	6,26 %	**3,95 %**
2	1920	57,7	600	900	2379	2439	2,52 %	2584	8,62 %	**5,95 %**
3		53,4	600	900	2379	2436	2,40 %	2607	9,58 %	**7,02 %**
4	1899	67,5	600	900	2379	2430	2,14 %	2612	9,79 %	**7,49 %**
5	1905	132,16	900	1350	3569	3663	2,63 %	3816	6,92 %	**4,18 %**
6	1882	17,6	600	900	2379	2565	7,82 %	2747	15,47 %	**7,10 %**
7	1882	130	600	900	2379	2502	5,17 %	2612	9,79 %	**4,40 %**
8	1883	47,55	600	900	2379	2563	7,73 %	2651	11,43 %	**3,43 %**
9	1883	48,14	600	900	2379	2568	7,94 %	2739	15,13 %	**6,66 %**
10	1900	28,84	600	900	2379	2607	9,58 %	2933	23,29 %	**12,50 %**
11	1900	6,14	600	900	2379	2784	**17,02 %**	2883	21,19 %	**3,56 %**
12	1900	9,99	700	1050	2776	2832	2,02 %	3075	10,77 %	**8,58 %**
13	1900	73,94	700	1050	2776	2790	0,50 %	3073	10,70 %	**10,14 %**
14	1900	70,1	700	1050	2776	2834	2,09 %	2961	6,66 %	**4,48 %**
15	1900	70	700	1050	2776	2928	5,48 %	3021	8,83 %	**3,18 %**
16	1910	29,49	600	900	2379	2556	7,44 %	2675	12,44 %	**4,66 %**
17	1894	37,3	600	900	2379	2522	6,01 %	2650	11,39 %	**5,08 %**
18	1894	41,8	600	900	2379	2541	6,81 %	2659	11,77 %	**4,64 %**
19	1894	28,9	600	900	2379	2522	6,01 %	2617	10,00 %	**3,77 %**
20		29,5	600	900	2379	2691	**13,11 %**	2733	14,88 %	**1,56 %**
21	1897	35,8	600	900	2379	2442	2,65 %	2627	10,42 %	**7,58 %**
22	1897	51,73	600	900	2379	2428	2,06 %	2590	8,87 %	**6,67 %**
23	1897	59,54	600	900	2379	2480	4,25 %	2621	10,17 %	**5,69 %**
24	1897	59,54	600	900	2379	2482	4,33 %	2626	10,38 %	**5,80 %**

Tab. 1:
Extract from the results of the measurements in Dortmund (U = circumference).
All sections under review here are greater in circumference and height than indicated in the asset plans. The difference in the measured sizes (between the minimum and maximum circumference) ranges from slight (up to 4 %, highlighted in green) through moderate (4 % to 7 %, highlighted in yellow) to great (more than 7%, highlighted in red).

Erratic changes of the internal size over the run of the sewer section as shown in fig. 5 can be identified in the video image from the optical inspection. In the same section, however, there were also gradual changes of size, as shown in fig. 6. This in part stealthy increase in circumference is not identifiable within the framework of the optical inspection. The exact information on the actual cross-section over the run of the sewer section acquired in the course of the project is relevant when planning further rehabilitation measures. Depending on the liner system, it could be necessary to split the section with the continuous increase in cross-section and to provide an intermediate manhole. As a result of this measure, liner systems with an optimum fit can be assured for all areas of the section with a heterogeneous circumference.

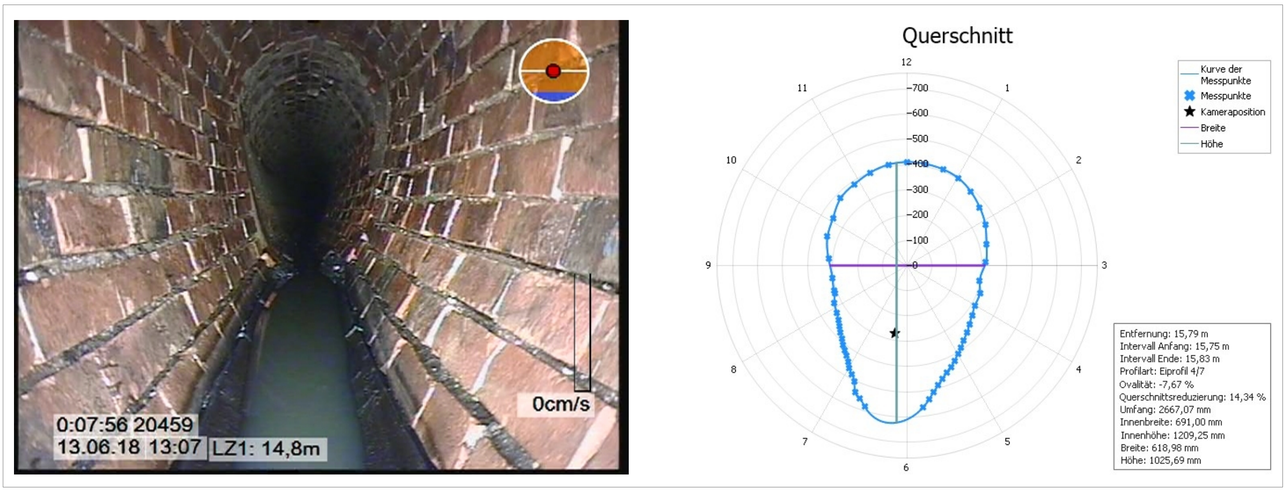

Fig. 5:
Left: Video image directly before the measuring point: erratic changes of internal size visible in the run of the section
Right: Cross-section of the pipe as an extract from the measured spiral on a level with the change in cross-section

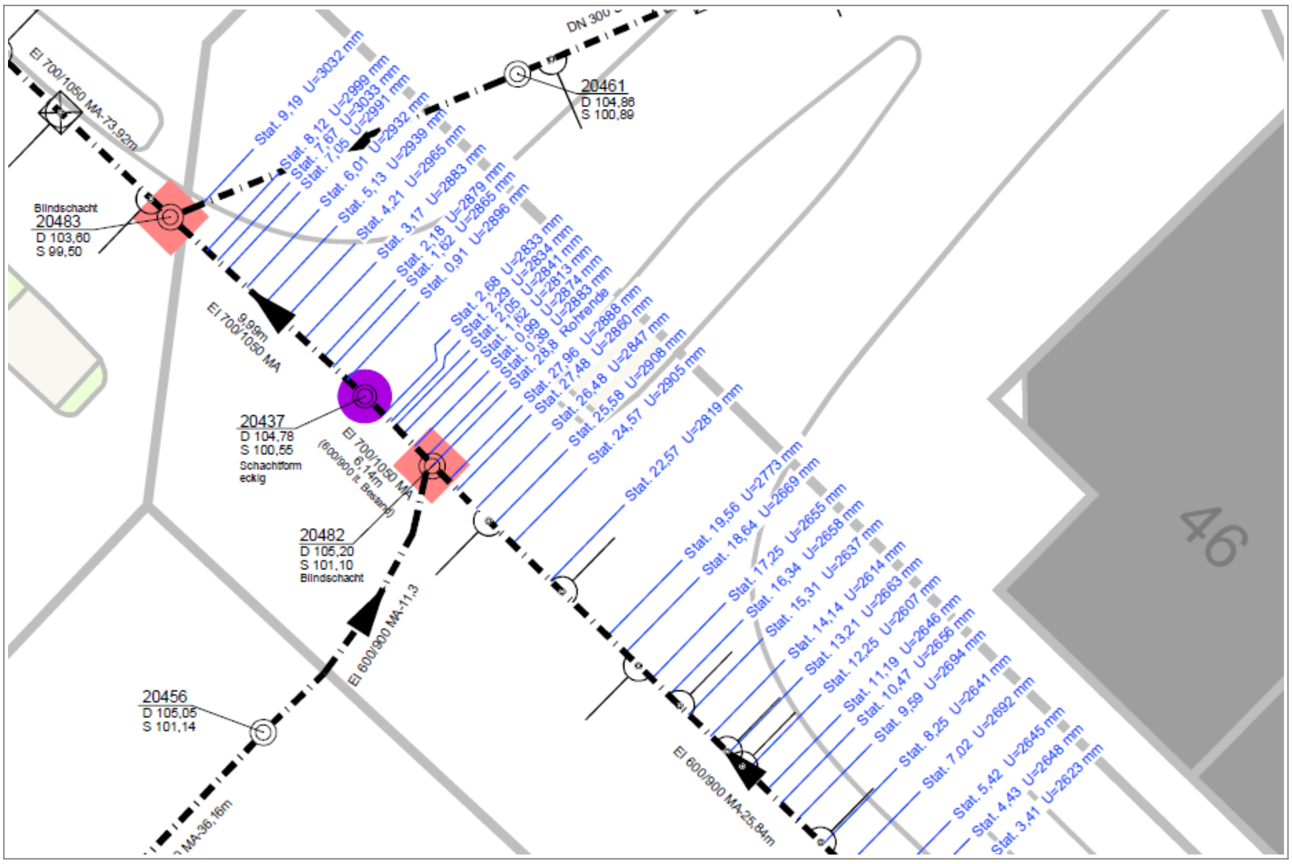

Fig. 6:
Extract from the site plan of the Dortmund Sewage Department: within the section, besides erratic changes in circumference (U = circumference), gradual changes of internal size were also ascertained. These were not identifiable in the course of the optical inspection but are relevant for the dimensioning of the liners.

The evaluations of the measurement results exemplified here by the planning engineers from VOGEL Ingenieure GmbH form a basis for the choice and the order dimensions of the liner system. If the actual cross-sections are known, the liners can be dimensioned and manufactured accordingly.

6.4. *Data Transfer to the Client*

The evaluations performed on the basis of the measured data were clearly presented by the IKAS evolution software with various possible views. The software generates a well-arranged report from the results of the laser scan measurement. This is fully integrated into the viewer software. All data such as videos and reports can be viewed coherently with the pipe cross-section analysis.

7. Conclusions and Future Prospects

Within the framework of the preparations for a continuous ovoid cross-section measurement by means of lasers, deposits should be removed by cleaning and during the laser scan loose deposits should be reduced to a minimum. A continuous, laser-supported cross-section measurement was able to be performed in the ovoids in Dortmund with the pan and rotate camera IBAK ORPHEUS 2. This was possible without any additional time being required for installing the laser. The evaluations performed on the basis of the measured data could be clearly presented and comprehensively analysed with the IKAS evolution software. The standing water in parts of the sewer could be cleansed from the measured values for the calculation of the internal circumferences. Data and therefore insight that by far exceed the scope of a purely optical inspection could be gained from the laser scan of the sewer sections. This applies in particular to determining the actual pipe cross-sections.

As Dortmund Sewage Department is planning the rehabilitation of the sewer sections with ovoid cross-section by means of a lining procedure, the information from the laser cross-section measurement is decisive for the choice and dimensioning of the liners. Determining the measured maximum and minimum circumference over the entire length of each individual sewer section enables a liner with a stretch behaviour that is optimally suited to the actual pipe cross-section to be selected in the further course of the project. This can prevent the liners from not adhering fully to the pipe wall due to insufficient stretch capability or from being damaged during installation. If liners cannot adhere to the entire circumference of the pipe wall during installation because the actual internal sizes are bigger than expected, a larger annular gap forms than is standardly supposed in the static calculation.[2] Depending on the actual stress conditions, this can lead to overstraining the liner in the course of its life span. Overstretching the liner during installation can also damage the inner foil so that the liner does not provide the required quality right from the beginning. In order to avoid these risks, the ordered sizes must be adapted to suit the actual pipe cross-sections.To avoid delays and variation orders, cross-section measurement and data evaluation in preparation for rehabilitation measures should already be performed at the planning stage.

VOGEL Ingenieure GmbH is currrently working on the implementation plan and the preparation of the tender documents. Further preliminary studies such as ground investigations and static calculations for the liner systems have been performed. All the acquired information is being integrated into a holistic rehabilitation concept. The declared target is to launch a call for tenders for the project in summer 2020 and to begin with the implementation from 2021 onwards.

2 For further information see the professional article by Markus Vogel (2018): 'Schlauchlining – bewährt, aber nicht trivial!' https://www.vogel-ingenieure.de/assets/Uploads/module/downloads/bbr-0708-2018-20-31-Vogel.pdf