Reliable data on rehabilitation requirements by means of selective sewerage inspection:

Profitable Forecast (Procedure Description AQUA-Selekt)

Almost every election is decided by around 6.30 pm – although only a fraction of the votes have been counted by that time. Complex extrapolations are what make this possible. Something similar is being developed by scientists at the Technical University in Aachen for sewer systems. Up to now rehabilitation has only been undertaken when the robotic eye has inspected the complete sewer system. Examinations carried out on the sewer network of the VW plants show that the condition of the entire system can also be assessed reliably by taking a sample. The automobile manufacturer has checked the costs of the TV inspection by 75 per cent. If the method is used in municipalities, treasurers could save millions of Deutschmarks every year.

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The rehabilitation of sewers is an unpopular subject for any treasurer. Municipalities spend approximately DM 46 per inhabitant every year on repairing worn-out sewers. Nevertheless, the rehabilitation carried out by cities and municipalities always lags behind that required: it is estimated that 16 per cent of the public sewers are defective in *one way or another*. With a network in Germany measuring 400,000 km and average rehabilitation costs of DM 1650 per sewer meter, rehabilitation requirements very quickly amount to a sum of over DM 100 billion.

If we also consider that more than 50 per cent of the sewers in the new federal states originate from the pre-war period (old federal states: approx. 23 per cent), it is clear what investments are be planned for in municipal budgets, not only now, but also in the future.

The picture is even more critical for the private network. Although there is little concrete data available, the Sewage Technology Association (ATV), for example, assesses potential damage in the 1.55-million-km private sewer system as considerably higher. Accordingly, the ATV estimates the rehabilitation costs at "clearly over DM 250 billion".

No costs, however, have as yet been spared when determining the condition of the sewers – as though funds for rehabilitation were unlimited: considerable costs are incurred for an across-the-board inspection of sewer systems and public branch lines alone, before any rehabilitation is undertaken. In addition, this procedure has many drawbacks: one of the biggest problems is the immense amount of time required to fully assess the condition of the network. Experience has shown that in federal states in which self-monitoring regulations have been introduced it takes around ten years. For federal states in which no scheduled inspection is required it is very difficult to estimate when a full inspection of the sewer system will be complete. As a rehabilitation concept can only be drawn up towards the end of the complete survey, a large part of the results gathered from the inspection is already out of date when the concept is drafted.

This means on the one hand that, without a rehabilitation concept, budgetary planning is full of inaccuracies over many years and, on the other, that the reaches classed as requiring rehabilitation must, as a rule, be inspected again before bids are invited, unless immediate measures have to be taken.

Relevance of influential features for municipal sewer systems and public branch sewers: information on the influential features printed in italics will generally not (in economic terms) be available. This has to be derived as far as possible, therefore, from other influential features (in the main year of construction and pipe material).

Sampling is very precise

These disadvantages can be avoided by inspecting a selective sample and then applying the classified condition to the entire sewer system. This is shown by initial examinations carried out on industrial drainage systems, e.g. at the VW plants in Wolfsburg, Brunswick and Emden (see box) [3]. In order to enable this method to be applied to municipal networks and public branch sewers however, several important questions still have to be clarified. For this reason, the Institute for Domestic Water Supplies at the Rhenish-Westphalian Technical University in Aachen (ISA) and Aqua-Ingenieure GmbH, Saarbrücken, are conducting a research project in cooperation with various sewer system operators. The project, which is sponsored by the Federal Ministry for Research, bears the title "Development of a method which can be generally applied for the selective primary inspection of sewers and branch sewers". In this connection the fundamentals for a method that can be generally applied for the primary inspection are to be drafted, and the forecasted condition values are to be examined by means of such an inspection.

Information on the condition of the sewer systems is required essentially for two planning targets:

1. as a basis for concrete, developed rehabilitation planning (individual reaches) and
2. as a basis for analyzing the condition and cost trend as well as the total extent of rehabilitation required on sewer systems and partial systems (across-the-board view).

An up-to-date inspection of the sewer reach concerned is on all accounts necessary for developed rehabilitation planning.

For an across-the-board view of the condition the structural state can fundamentally be determined by a

- full survey of the condition of the system or by a
- representative inspection of selected reaches with subsequent extrapolation for the complete sewer system.

The across-the-board inspection of the sewer system that is at present customary, without representative and prognostic evaluation, is an expensive and inefficient strategy [4]. This can be illustrated by a simple arithmetical example: if we assume that the useful life of a sewer is between 51 and 100 years, approximately one to two per cent of the entire system must be rehabilitated a year. If we also presume that approximately ten per cent of the system is inspected a year, then only 10 to 20 per cent of the findings gathered from the inspections result in rehabilitation measures being implemented. In other words: the sewer robot passes a reach five to ten times before it must actually be rehabilitated.

This is unnecessary as the current rehabilitation requirements can be estimated very precisely by taking a representative sample covering 15 to 30 per cent of the complete sewer system. This primary survey of the system condition by means of sampling and its representative extrapolation provide a reliable basis for planning, not only at considerably lower cost, but also at much shorter notice.

VW: fast test certificate for the sewer system

Since production must continue and in-plant logistics must not be interrupted, sewer rehabilitation in industrial plants can become a real drag. This was the case at the Volkswagen plant in Wolfsburg, where an across-the-board inspection of the sewer system had also been avoided for reasons of cost. The sewer system originated in 1938, has been gradually expanded and has a total length of 350 km, of which 70 per cent is located under the production area. Small-sized branch sewers add up to 230 km, and the mains and collecting mains which can be accessed via the inspection chambers make up 120 km.
The engineering consultants **Aqua-Ingenieure, Saarbrücken**, carried out a selective inspection of the sewers at the plant. VW wanted to know, in particular, what rehabilitation costs were to be expected in the medium term. The evaluation of the samples was extrapolated for all sewers and showed that 51 per cent of the system was in the range of the condition categories 2 to 6 (1 = severest damage; 6 = no damage). On the other hand the engineering consultants were able to rule out the possibility with 95 per cent certainty that there was any serious damage in these parts of the system, damage that

required monitoring at short notice and rehabilitation. The extrapolation established that all condition categories could be represented in 33 per cent of the remaining system. Concerned here are, above all, the old system parts on which rehabilitation will be concentrated in the future. According to the engineering consultants, it was possible to cut the costs of sewerage cleaning and TV inspection by around 75 per cent in comparison to a conventional method. These funds are now to be used directly for rehabilitation.

Examinations of various sewer systems

The entire sewer system is also surveyed bit by bit with the selective inspection method. In comparison to the conventional method however, inspection is carried out selectively, dependent on the forecasted condition. By this means, inspections are largely made just immediately before the forecasted rehabilitation requirements.

In this way, repeat inspections can be dispensed with to a large extent. This method can also be applied in the states in which, as a rule, an across-the-board inspection is prescribed by self-monitoring regulations.

That is to say insofar as faultless monitoring is guaranteed in another way, the authorities may approve this method on the strength of appropriate exceptional rules.

In order to be able to obtain generally valid information, systems with different structures will be considered:

- a large and medium-sized municipal sewer system (city of Brunswick)
- a rural sewer system (municipality of Marpingen, Saarland),
- connecting interceptors outside a locality (Entsorgungsverband Saar [waste disposal association]) and
- public branch sewers (city of Ingolstadt).

Methodology of selective primary inspection: using the selective inspection strategy method, a representatively selected part of the sewer system or the branch lines is first inspected and classified. On this basis, information can be obtained on both the condition of the entire system and on that of each single reach. The characteristic features of the respective sewer system are taken into account by the fact that sample selection and extrapolation of the condition classification are carried out each time for individual types of reach with similar feature formation, so-called layers. The following steps are necessary to carry out a selective inspection:

- layering of the sewer system,
- selection of sample to be inspected,
- inspection of sample, classifying its condition and
- statistical evaluation of the condition classification and application of the results to the entire system (forecast).

Layering of the sewer system: as municipal sewer systems and public branch sewers tend to be heterogeneous in terms of their characteristics, it is necessary to layer the system to forecast the condition of the sewer.

Layering facilitates evaluation

The aim of layering is to obtain several basic wholes that are as homogeneous as possible with regard to damage distribution, and thus enable a statistical evaluation to be made (Illustration 1). It is carried out by means of differentiating between influential features. Influential features are the characteristics of a reach that can be expected to affect its condition (e.g. pipe material, year of construction, the location in the transport infrastructure or, if applicable, implemented rehabilitation measures).

In addition to the age of the reach, the year of construction also includes the technical standard existing at the time of construction with regard to the quality of the material (pipe strength, sleeve design and sealing system) and execution, and thus gives a picture of the aging characterstics of a

reach. With regard to the relevance of influential features a distinction is made between influential features that should on all accounts be surveyed within the scope of a selective inspection and those that vary in importance, depending on local marginal conditions, and perhaps can even be ignored completely (see Table p. 26).

Cost savings – an arithmetic example

The cost savings achieved by means of a selective primary inspection as compared with the conventional, across-the-board inspection can be shown by taking a 100-km-long sewer system as an example. This estimate is based on the following assumptions:

- 20 per cent of the sewers are in need of rehabilitation
- the costs of the TV inspection are DM 6 per meter.

Neither price increases nor interest are taken into account.
Conventional method: with the conventional method it is assumed that, in compliance with the self-monitoring regulations, approximately ten per cent of the sewer system is inspected a year. Thus, the amount of time taken for an across-the-board primary inspection is ten years. Inspection data that is more than five years old can no longer be used for planning rehabilitation measures and inviting bids for such. A new inspection is necessary in this case, which means that before bids for the rehabilitation work are invited, a tenth of the sewer system length must be inspected again if we assume that 20 per cent of the system is in need of repair. These costs are apportioned to the first decade. On the basis of these assumptions the total costs of the conventional method amount to DM 660,000.
Selective inspection: with the selective inspection approximately 20 per cent of the entire sewer system must be inspected to obtain a qualified statement on its condition. This inspection takes around two years. First it is necessary to layer the reaches via the sewer inventory; after the inspection has been made, the information gathered on the condition is statistically evaluated. These engineering services are, in the main, independent of the size of the sewer system. They take about eight months and are estimated here as a lump sum of DM 80,000. After the selective primary inspection, 20 per cent (= four km) of the damaged sewers have been surveyed; before inviting bids for rehabilitation, therefore, it is necessary to inspect the sewers with forecasted rehabilitation requirements. This is a distance of 16 km.
Following the selective primary inspection, a selective inspection that is dependent on the condition is carried out as a further survey of the sewer system. These differentiating intervals between inspections, the presumed average being 25 to 30 years, are quite clearly longer than the ten-year cycle of the conventional method. A length of approximately three km is inspected, therefore, each year. The annual costs of an inspection thus amount to around DM 9000.

After the influential features that are considered relevant for a sewer system have been determined, a differentiation between them is made. For statistical and economic reasons this must be done in such a way that layers which are as homogeneous as possible are obtained on the one hand and, on the other, that there are as few layers as possible (differentiation combinations). Thus, depending on the respective marginal conditions, it is necessary to reach a suitable compromise. **Determining the sample:** samples must be fundamentally random and representative with regard to the basic whole. The reaches to be examined as samples, therefore, are randomly selected in the required numbers from the system sections that represent an appropriate layer, and then inspected. In addition to the samples being random however, logistical aspects are to be considered. An inspection of reaches that are spread separately across the entire sewer system should be avoided. Following the inspection, the condition of the sample is classified, this classification then being the basis for the forecast and for further statistical considerations.

Cost advantage is determined

Evaluation of results and application to entire sewer systems: the results from the classification of the condition of the sample are then extrapolated for the respective basic whole (single layer) and applied to the entire sewer system. The following statistical information on the condition is thus available:
forecasted condition distribution in the individual layers, in the entire sewer system or differentiated according to individual features and
estimated values related to reaches with regard to condition:
- an arithmetical average or median of the condition category, specific to the layer,
- a minimum condition for each reach which, with a certainty to be defined, is not to be fallen below.

Project development and the need for examination: the individual phases of the project correspond with the described basic steps involved in carrying out a selective primary inspection. The current standing is that the fundamental influential features have been determined, and general information on their differentiation can be given which, in addition to the local marginal conditions, is the basis of the layer formation in the sewer systems of the municipalities concerned. Inspection and classification of the sample will take place in the course of this year.

Statistical evaluation of the condition classification will enable generally valid information on the following points to be obtained:

Extent of inspection: the absolute extent of the inspection required for a sufficiently precise forecast is dependent on the sewer system structure and on the distribution of the condition categories in the individual layers. The evaluation of industrial sewer systems has provided some initial findings in this respect (see box p. 77). To what extent these can be applied to municipal systems is to be clarified as the project proceeds. Moreover, an examination will be made to determine on which marginal conditions the spread of the condition categories is dependent. The aim is to enable the sewer system operators to estimate as exactly as possible the extent of inspection required and the cost savings connected with the selective primary inspection by analyzing the structure of their sewer system.

Relevance of, and differentiation between, influential features: the number of layers to be considered increases as the number of influential features and distinctions under consideration increases. Consequently, the layers have fewer reaches and are thus more homogeneous. As the sample volume to be considered is essentially absolute, i.e. independent of the number of reaches in a layer, the relative sample volume also increases: the economic advantage of a selective primary inspection is reduced. An evaluation of the inspection results will thus examine which influential features are indispensable or perhaps could be ignored, and on which marginal conditions this relevance depends. The same applies to differentiating between the influential features.

Forecast of condition: the condition forecast carried out in the scope of this project will be examined on the basis of a complete inspection of selected layers. It will then be possible to state which statistical distribution curves can best represent the condition distribution in the sewer system.

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