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Estimation Of Residual Service Life For Existing Sewerage Systems

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Summary: The cost of maintaining public sewer systems in Germany has been estimated at about € 50 billion. According to German environmental laws, the technical state of sewers has to be checked regularly by means of inspection technology. The condition of sewer pipes and pipe joints are evaluated according to the scale and the effects of damage. The determined damages are assigned to one of five different damage classes. The damage classes range from very serious to negligible.

In a second stage, the status of sewer sections is evaluated according to the greatest damage. These evaluation data are installed in a sewer database according to belonging functionality and stability variables such as significance of sewer section, hydraulic capacity, overflow frequency, material, construction year, geometry, size of covering and traffic load situation.

In a third stage the correlation is graphically described between the network sections and the year of construction and different functionality and stability variables. The aging curves were derived from the available inspection data and the construction year for each status class. The average residual service life of the sewer section is represented by a vertical line between the real age of the sewer section and the point of intersection with the aging curve of intervention status class. The different intersections on the horizontal line with the aging curves of different status classes indicate the ages at which the section is likely to drop to the next class or, going back in time, came from the previous class.

The example of a small town shows how the acquisition of data and the evaluation of damaged sewers in a municipality is carried out and illustrates which priorities have to be established during the maintenance of sewer networks. The model city of 8,000 inhabitants is situated in the middle of Germany. The sewer network comprises around 25 kilometers with 700 individual sewer reaches. In 1998 the total sewer system was optically inspected. The results of the inspection serve as the basis for a database.

Using inspection results from the model city and the application of the cohort survival model for stock forecasting, a prognosis for the lifetime of sewer pipes has been developed. The first results show that the average lifetime of concrete pipes for drainage of combined waste water can be estimated at 100 years. The average service life of stoneware pipes, both for drainage of dirty waste water and for combined waste water, amounts to 120 to 150 years using these evaluations. Municipal authorities are able to reach decisions regarding inspection and maintenance cycles.

Keywords: Sewer Status Assessment, Predictive Rehabilitation Planning, Aging Process, Forecasting, Service Life

1 INTRODUCTION

The orderly maintenance of sewer systems requires systematic and regular optical inspection and documentation of the results. Generally, the inspection is conducted by remote control CCTV camera systems, inspection experts, and, in some cases, a leak test. The inspection of the total sewer network district usually must be carried out every ten years. In order to document the results, video recordings, photographs, test certificates and sketches have to be produced (Buetow *et al.* 1995).

As a result of the inspections, local councils can decide themselves upon subsequent construction or repair measures. The urgency of the necessary measures is determined by the danger to environment, functionality and stability. According to an investigation from 1997, about 18 percent of the German public sewer network, which consists of different pipe materials (concrete, stoneware and plastic) and has a total length of about 440,000 kilometres, is considerably damaged due to its partially high age (Kaempfer e*t al.* 1999).

The rehabilitation of these sewers would cost about € 50 billion. At the present time only 3.5 percent of this is available. If one considers that each year the aging process causes at least one additional percentage point of network length to become urgently in need of rehabilitation, then one can easily realize that significant improvement of sewer conditions cannot be achieved. Therefore an effective improvement of the condition of sewer networks with the well-known limited financial resources necessarily requires early recognition and timely and thus inexpensive removal of incipient defects (Kaempfer *et al.* 2000).

It is accepted that, due to sewer damages, about 500 million cubic meters of contaminated liquids leak into soil and ground water every year (Buetow *et al.* 1995). Therefore, the main goal of rehabilitation planning should be to predict sewer deterioration in advance and thus avoid gradual loss of intrinsic value. Long term maintenance at minimal cost must take into account the optimal residual service life of the sewer network system. This requires early recognition of incipient damages.

2 STRUCTURE OF EVALUATION MODEL

The example of the model city Stadtilm shows how the acquisition of data and the evaluation of damaged sections in a municipality is carried out, and illustrates precisely which priorities have to be established during the repair of sewers. This model city is a small town of 8,000 inhabitants in the middle of Germany. The sewer network comprises around 25 kilometers with about 700 sewer sections, primarily for the drainage of dirty waste water (8 %), rainwater (6 %) and 86 % combined sewers (Kaempfer *et al.* 2000).

The total sewer system was inspected two years ago. The age and structural materials are typical for the historical development of the infrastructure of small towns in the middle of Germany built at the turn of the 19th century. The results of the inspection serve as the basis for the repair of the sewer network, for which an annual budget of only € 150.000 is available. A comprehensive data base, incorporating the results of the inspection, was established.

The evaluation model was developed as a part of the project "Residual Service Life for Sewerage Systems", at the Institute for Material Research and Testing at the Bauhaus University Weimar (Kaempfer *et al.* 2000). In order for such an evaluation model to be used by a municipality, it must be relatively simply constructed and has to establish clear priorities that can be put into practice. The evaluation model can be divided into three stages of development. First, the individual instances of damages are evaluated, then the influence variables with regard to their effects of damage on environment, functionality, and stability are estimated, and finally an overall evaluation of the situation is made.

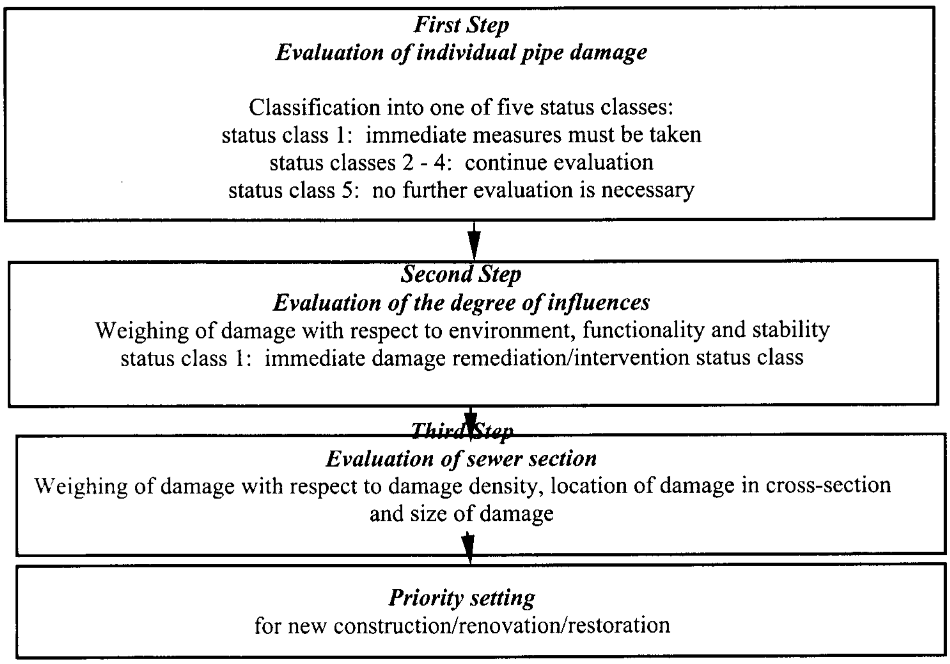

Figure 1. Diagram of the evaluation model for damaged sewer sections

Each instance of damage is assigned to one of five different status classes. This classification requires the knowledge of the exact geometrical dimensions of the damage, such as width and depth of cracks, fractures, and defective pipe connections.

The basis of the classification of sewer section status is its most recent machine-readable inspection report, and for each problem detected it contains the type and extent of damage, as well as the location in cross-section and in direction of flow. Each instance of damage is assigned to one of five damage classes from status class SC 1 - very serious damage- to status class SC 5 - negligible damage. During evaluation of the individual instance of damage, the effects on the environment, functionality and stability are assessed.

The classification into different status classes is made on the basis of a damage catalogue (Kaempfer *et al.* 2000). The rehabilitation priority for the entire sewer is determined by the level of damage of each section. The determining level is thus the level of the most serious damage. If the rehabilitation priority drops to the intervention class, the section is in urgent need of rehabilitation. The intervention class can also depend on location. The rehabilitation priority bears no relation to the remaining lifetime of the sewer section. The forecast of rehabilitation priorities uses a model of the local aging process or is determined by inspection findings and the construction years of all the sections (Hochstrate 2000).

The aging process of sewers varies from place to place with regard to average service life. It is nevertheless evident that, for sewer sections, the past speed of aging will be maintained in the medium term future. Repeated inspections offer the opportunity to recognize changes in the aging speed and to generate forecasts that take this information into account.

The modeling of the aging process of sewer sections is based on the fully developed statistics to compute human survival probabilities. Sewer sections and human beings have similar life expectancies, but a completely different distribution of age at death. Many sewers fail between the age of 0 and 10 years because of faulty installation and construction defects or overloads. On the other hand, some sewer sections, which have already attained an age of 100 years in good condition, have a higher survival probability than a new one that has recently been laid.

In order to evaluate the expected residual lifetime of sewer sections it is important to consider the individual status classes. The range of status values is regarded as a constant against which a continuous function of age is plotted. Figures 2 and 3 show examples of the change-of-condition functions of different pipe materials for the five status classes. They can be used to estimate the medium service life of a sewer section or to ascertain the amount of time it will spend in one of the five status classes. Each sewer system must have its own set of change-of-condition functions, according to its historical infrastructure development, based on the inspection data base.

The change-of-condition is updated as new inspection data becomes available. The conditions for estimation of residual service life for existing sewer sections are the knowledge of both the construction and inspection years and the availability of status class values for rehabilitation priority. On the basis of the normatively established intervention status class it is possible to forecast the repair year and the year of complete rehabilitation. Forecasts of time of intervention are obtained by the point of intersection of the vertical line (year of construction) with the aging curve of status class one.

3 FORECASTS OF SEWER STATE

The evaluation model has been installed in a central sewer system database. All data was entered into the sewer system database that allowed a comprehensive evaluation of damage to the sewer system with respect to stability, functionality, and environment. Besides damage data, a number of other essential data were recorded, such as material and construction parameter, year of construction, covering depth, and traffic loads. All damages were allocated to the corresponding damage classes.

Most damages in Stadtilm are allocated to status class 3 and 4. The number of cases of damage that needed to be dealt with immediately was surprisingly high. As this large number of cases cannot be remedied at once, it must be decided which rehabilitation measures are most urgently necessary. The location of the worst cases of damage in the city is of essential importance for planning maintenance work and infrastructure maintenance planning generally. The sewer database was linked to a GIS system.

The modelling of the aging process of sewer networks is based on change-of-condition functions. These functions were derived from the available inspection data and the construction years. The vertical axis in diagrams 2 and 3 shows the proportion of construction years.

The horizontal axis represents the sewer section age in years. From these diagrams, the average service lifetime of sections of definitive age can be obtained. The residual lifetime can be determined by the period between data for the vertical line at the age of x years for a defined status class of the sewer section and the point of intersection of the horizontal line with the defined intervention status class (urgent rehabilitation priority SC 1). Figure 2 gives an example of the network transition function for the Stadtilm project. The curves were derived from the inspection data of the whole sewer network with construction years.

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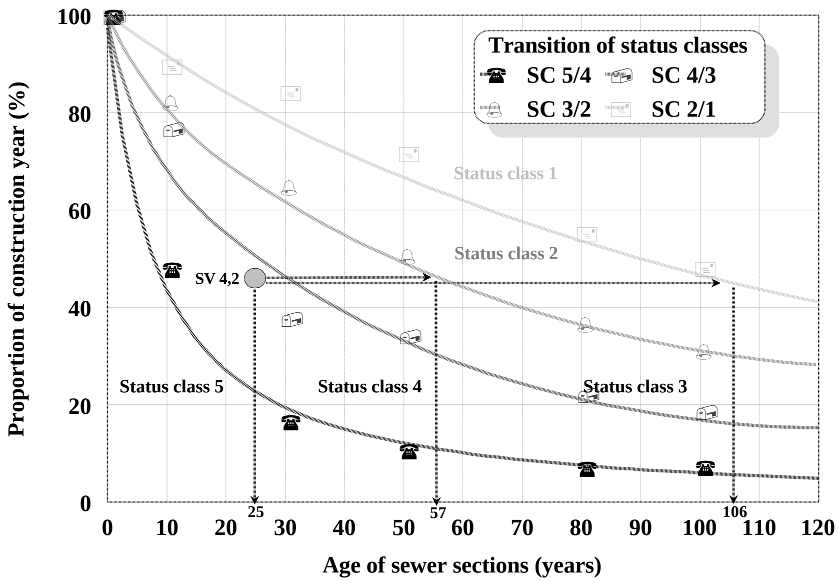

Figure 2. Status transition functions for local aging process of concrete sewer sections

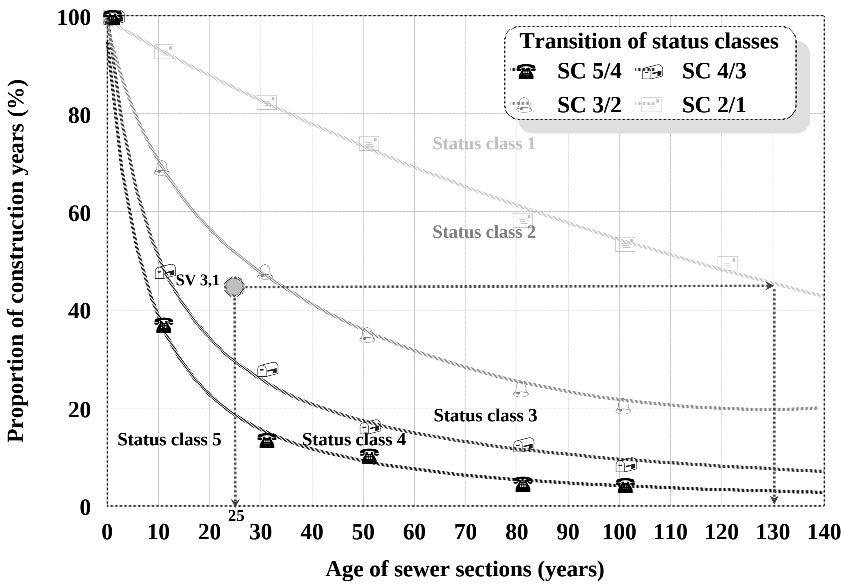

Figure 3. Status transition functions for local aging process of stoneware sewer sections

Concrete pipe sections, which are today 25 years old, will serve as an example (see Figure 2). On the line of inspection age 25 interpolate the status value SV 4,2 between the points for status values 4 and 5. Draw the horizontal SC-path. Transition to class SC 2 occurs at age 57 and to status class SC 1 at age 106.

The average residual service life of concrete pipe sewer sections is accordingly, on average, 32 years in water preserve area and 81 years in normal waste water situation. Figure 3 shows the change-of-condition function for the local aging process of stoneware sewer sections. The change-of-condition functions describe the average statistical service life of sewer pipe materials in one status class.

The presented regression lines are determined by statistical calculus of observation. The statistically-determined values amount from 60 to 94 percent. The determined aging curves apply only to the drainage district. In other cases the curves will assume other behaviour.

Contrary to the results so far the regression lines of aging show a pronounced degressive development. The sojourn time increases in decreasing status classes. The average service life of concrete sewer sections amounts 100 years. In the case of drinking water safety areas, the effective time period of repair is 58 years. Compared with concrete pipe sewers the aging process of stoneware sewer sections shows a more degressive course. Stoneware is a more brittle material, a characteristic which can result in sudden material failures.

The average retention time of stoneware sewers in the status classes from SC 5 to SC 3 is lower in comparison to concrete sewers. On the other hand, the sojourn time to achieve the intervention status class SC 1 is about 50 percent higher than that of concrete pipe sewers. The total residual service life of stoneware sewer sections ranges from 120 to 150 years. Especially during or directly after installation of stoneware pipes, a high amount of sewer damages arises (Kaempfer *et al.* 2000).

The estimation of residual service life of sewer sections forms the basis for advanced planning of sewer inspection, the representation of the sewer section condition expected in the future and for the yearly budgeting of rehabilitation measures.

4 REAL AND ARTIFICAL AGING OF PIPE MATERIALS

Manufacturing methods and pipe material parameters depend on construction years. From 158 building sites, different kind of pipe materials were removed to determine material parameters for the natural aging process. The investigated pipe materials were installed between 1900 to 1985. The vast majority of pipes, installed during this period were stoneware and concrete pipes. The material parameters for concrete pipes, that were primarily tested, were comprehensive strength, porosity and water absorption. The tensile bending strength, the porosity and structure failures were analysed on stoneware pipes. Table 1 shows, for example, average material parameters of different naturally-aged concrete pipes from combined sewers.

Table 1. Material parameters of real aged concrete pipes from combined sewers

Age of samples (years)	*Compressive strength (N/mm²)*		*Porosity (%)*	*Water absorption (%)*
	at spring line	*at the crown*		
70	34	28	16,2	1,98
40	32	25	11,1	1,70
25	42	32	16,7	2,51
15	52	45	16,5	3,13

The average compressive strength of analyzed naturally-aged concrete samples is beyond all exceptions. From the damage grade of concrete pipe material it is possible to determine the residual load-carrying capacity. Even in reduction of pipe wall thickness until 60 % of original wall thickness the residual load-carrying capacity may be sufficient.

To simulate resistance to biogenous sulfuric acid attack, a very simple test procedure has been developed that provides an authentic demonstration of how sulfuric acid attacks in dirty and combined sewers. In these tests waterlogged specimens are weighed and stored in plastic containers. Each container is filled with diluted sulfuric acid (pH 2). The pH value of the acid bath is kept constant over 70 days. This test procedure is suitable for decision on service life under time-accelerated conditions.

All six days the specimens are removed from the solution, then stored under running water, vigorously brushed off and all loose parts removed. After this the specimens are weighed and stored, following the same procedure. This operation corresponds to practical conditions of cyclic flooding in combined waste water sewers after downpours. The acid is circulated permanently. In order to keep the pH value constant, concentrated acid is added. The acid bath is restored after each storage cycle (Kaempfer *et al.* 1999).

Several types of stoneware and concrete pipe materials of very different ages were investigated. The undamaged cross-section, the residual weight, the residual compressive and tensile bending strength and the acid penetration depth at different exposition times in diluted sulfuric acid were determined, as to be able to draw conclusions about the further aging process of older pipe materials. Figure 4 show the development of weight losses of time-accelerated aged concrete pipe material in diluted sulfuric acid.

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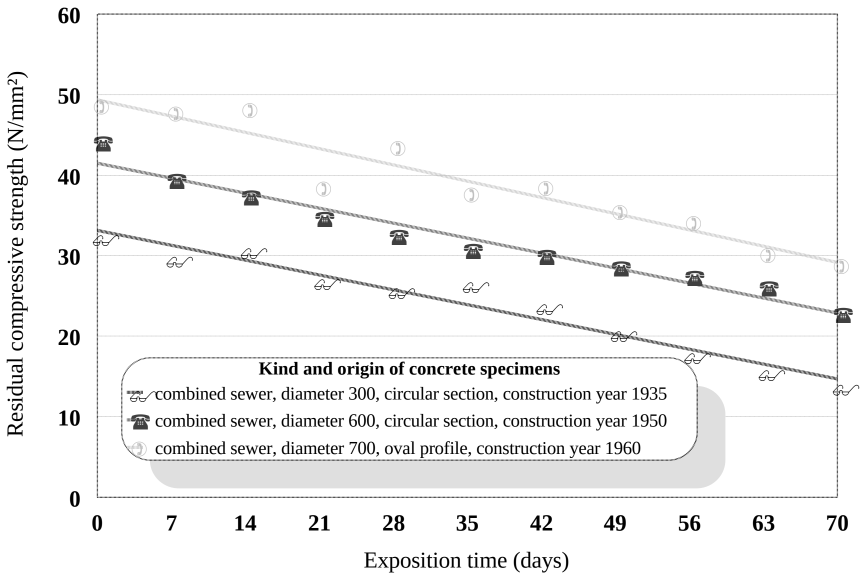

Figure 4. Residual compressive strength of concrete pipe materials versus exposition time in diluted sulfuric acid

5 SUMMARY

The forecasts of the aging process for different pipe materials make use of a model of the local aging process based on inspection findings, pipe material parameters determined by naturally-aged pipe materials, time-accelerated laboratory tests and construction years of all the sections. The aging process of sewers varies from place to place with regard to mean length of use and relative sojourn times in status classes.

Local aging processes of sewer sections cannot even be causally explained, so diverse are the interaction between types of construction, manner of installation and the uses that are made of them. Thus it can be assumed, that a section's past speed of aging will also be maintained in the medium term future.

Determination of parameters on naturally-aged pipe materials and time-accelerated laboratory tests offer the opportunity to recognize changes in aging speed and to generate forecasts that take this information into account.

6 REFERENCES

1. Buetow, E. & Ostmann, R. 1995, 'Municipal experience in the use of an assessment model for determining priorities when repairing leaky sewers', Hamburg, Germany, 1995, International NODIG '95, Conference Documentation, pp. 423 – 427

2. Hochstrate, K. 2000, 'Sewer Status Assessment by Rehabilitation Priority, Intrinsic Value and Functionality as Basis for Forecast Supported Inspections and Predictive Rehabilitation Planning', Hamburg, Germany, 2000, 6th International Pipeline Construction Show 2000, Proceedings, pp. 548 - 557.

3. Kaempfer, H.W & Berndt, M. 1999, 'Estimation of service life of concrete pipes in sewer networks', Vancouver, Canada, 1999, 8th International Conference on Durability of Materials and Components, Proceedings, pp. 36 - 45.

4. Kaempfer, H.W., Berndt, M. & Voigtlaender, G. 2000, 'Analyse der Restnutzungsdauer und Bestimmung des Erneuerungsbedarfs von Abwasserleitungen am Beispiel einer Thueringer Kleinstadt', 9. Konferenz Innovativer Rohrleitungsbau, Weimar, Germany, 2000, Proceedings, pp. 49 – 55

5. Kaempfer, H.W & Berndt, M. 2000, 'Ermittlung der Restnutzungsdauer von Beton- und Steinzeug-rohrleitungen am Beispiel einer Thueringer Kleinstadt', WAR Darmstadt/Weimar, Germany, 11. Gemeinsames Seminar Abwassertechnik, Conference Documentation, pp. 20 - 34