Rehabilitation of waste-water manholes: Large-scale tests and in-situ studies

Manholes in IKT's large-scale test facility

IKT's recently completed research report on the "Rehabilitation of waste-water manholes" focuses on two central topics: the sealing of the manhole structure and in- and outlets, and coating using mineral and polymeric systems.

Sealing and coating of manholes

There are around ten million waste-water manholes located in public traffic surfaces in Germany. Leaking manholes result not only in exfiltration of waste-water; if the groundwater table is in contact, significant quantities of infiltration can also enter, thus impairing the cleaning performance of treatment plants and storm water tanks. In addition, waste-water manholes are in many cases the citizen's only visible "interface" with the drain and sewer system. Defects here can cause hazards for traffic.

Manhole cover: the visible interface with the drain and sewer system photo: unikation, photocase.com

In co-operation with municipal system operators, IKT has developed the "Waste-water manholes" research focus, which receives decisive support from the NRW ministry of the environment. Two essential questions of this research focus have been studied intensively in the recently completed "Rehabilitation of waste-water manholes" [1] sub-project: sealing of the manhole structure and the in- and outlets, and coating using mineral and polymeric systems. The prime emphasis here was on the robustness of the methods and materials used in practical service, and performance under external water pressure during infiltration rehabilitation.

The project was monitored by a steering committee representing thirty-five system operators, and continuously orientated around their practical requirements. Selected products and procedures were analysed in the context of in-situ projects, 1:1 scale tests and supplementary detailed analyses.

All results can be downloaded from the Internet at: www.ikt.de (German Version)

Project target

The prime target of the project was that of obtaining substantiated knowledge concerning the factors influencing quality in sealing and coating projects, in order that this knowledge could then used by the system operators as a guide for further decision-making. This applied to the complete procedure, from the tendering and award-of-contract stage, up to and including acceptance inspection of rehabilitation work, including Quality Assurance provisions.

Suitable coatings already applied were firstly examined and submitted to numerous quality tests, in order to determine the effects of multiple years of exposure to operating conditions. In addition, sealing work on manhole structures and pipe joints were observed on site. The results of this, and perceptions gained from earlier research projects [2], were then used for the selection of suitable materials, methods and boundary conditions for the subsequent large-scale tests and supplementary laboratory analyses.

Sealing work in practice: cementitious waterproof plugging compound

The large-scale (1:1) tests investigated, in particular, the performance and robustness of sealing and coating methods under defined boundary conditions, which were identical for all the rehabilitation work. Special time-compression effects were applied across a period of five months, in order to permit study of the long-term behaviour of the renovated waste-water manholes under exposure to external water pressure.

Waste-water manholes

Further specific questions, such as the mechanical load-bearing capacity of repaired pipe joints, the behaviour of cavities under exposure to external water pressure, and the effectiveness of repair products for mineral coating systems, were answered on the basis of supplementary laboratory analyses. Activities were rounded off by a cost-effectiveness analysis, the use of innovative inspection procedures and practically orientated notes for planning, recommendations and training programmes.

Waste-water manholes: civil-engineering characteristics

Renovated waste-water manholes are complex civil-engineering systems. The assignment of specific damage and defects in renovation quality to causal damage/defect effects on the basis solely of in-situ observations is correspondingly scarcely possible. Previous research projects [2] had already shown that there are diverse factors capable of influencing the robustness and quality of the "renovation result", including, for example, deficiencies in preparation and performance of the renovation, and also failure to take account of structural loads and/or civil-engineering boundary conditions. Particular importance therefore attaches to understanding of the civil-engineering (system) characteristics of a renovated waste-water manhole; this applies, in detail, to the following:

Loads

Every civil-engineering system is affected by the loads acting on it. These may be of a purely mechanical, or also of a (bio)chemical nature. The soil load exerted on the structure, the level of the groundwater table and the dynamic traffic loads acting on the structure may be mentioned here, by way of example, for manhole structures. Exposure to chemical loads exerted by the conveyed fluid also play a role.

Material properties

The properties of the materials used both for the manhole structure itself and for the sealing/ coating system are of great importance for the character and performance of the structure as a whole and, in particular, for its mechanical strength, surface quality and chemical resistance.

Component and structural geometry

Waste-water manholes generally take the form of single-shell cylindrical elements with side in- and outlets. This geometry may be significantly modified by sealing or coating work. Sealing operations using injection methods, for example, generate voluminous foreign bodies in the surrounding soil, thus decisively altering the geometry outside the manhole structure itself. Coatings are intended to bond permanently with the substrate material, and thus modify the wall thickness and structure. Significant changes can also occur here in the course of time, as a result, for example, of the detachment of the coating, associated also with blistering caused by external water pressure, and/or the detachment of injection foreign bodies due to fluctuating groundwater tables.

External interactions / boundary conditions

Loads, material properties and structural geometry may also interact closely with other influencing factors and boundary conditions. Examples of this can be found in the compaction of the surrounding soil, and in alterations to the road formation and the underground zone.

As-completed/renovated manhole conditions

The relevant loads, material properties and geometry of a waste-water manhole are subject to changes over time as a result of the construction and/or renovation process, and the subsequent operating phase. The materials used are generally subjected as early as their development phase to comprehensive laboratory testing in order to determine their (time-dependent) material properties under exposure to mechanical and chemical loads (see [3]). The central focus of observations is therefore on process-engineering influencing factors, application-specific loads (and the groundwater, in particular), and the geometrical characteristics of the renovated systems.

The as-completed/renovated manhole conditions observed in the in-situ and laboratory studies can be differentiated as follows, using the example of the coating processes:

A system operator's manholes are inspected in the context of a condition survey, and the need for renovation is determined. It focuses, in general, on leaking masonry or concrete manholes, usually with a circular cross-section and various points of damage, including, for example, isolated and larger-area superficial damage, leaks in the pipe wall, and leaking inlets. The ingress of water may vary greatly, depending on the continuously fluctuating groundwater table. It must also be remembered that the connecting pipes may consist of different materials; in addition, considerable levels of moisture and of wall fouling must also be anticipated in a waste-water manhole.

Manhole renovation in practice

On the basis of this scenario, sealing provisions will now be performed, in order to temporarily restore the manhole's tightness. The visible leaks in the manhole will be systematically sealed using the most diverse range of materials and methods up to the level of the current groundwater table in order to achieve this. Mineral- and polymer-based materials are used for this purpose, and are either applied manually to the inner walls of the manhole, or injected into the manhole surroundings using injection packers and pumps. The geometry of the structure is generally significantly modified during these processes. Such work is normally performed during the summer months, when groundwater tables are low.

After successful sealing of the manhole, the manhole walls are firstly submitted to intensive substrate preparation, in order to make them suitable for coating. The aim of such preparation is, on the one hand, the removal of fouling, such as grease and loosely adhering deposits, from the substrate while, on the other hand, it is necessary to create a surface which will enable the coating to bond permanently with the substrate. For this purpose, the aggregate particles in concrete manholes should be visibly exposed, in order to provide the largest possible surface area for bonding. Reprofiling may also be necessary if significant surface irregularities, cavities and/or spalling have occurred. A specific substrate moisture level, depending on the coating material, must then be achieved by drying (in the case of polymeric coatings) or of moisturising (in the case of mineral coatings).

The structure is restored to its "freshly renovated" state by means of the coating and the finishing work. The coating may be applied to the manhole walls either manually or mechanically, or both. The interaction of the material and the method used are of particular importance in this context. Mechanical application, for example, necessitates material properties different to those required in manual coating using a pointing trowel and a smoothing trowel. Particular care is necessary on the ladder irons and at the in- and outlets. After-treatment of mineral coatings is generally necessary, in order to prevent cracking and assure optimum adhesion.

Complete curing (hardening) of the materials applied, completion of all finishing work and after-treatments is followed by acceptance inspection. This will involve visual inspection of the coating, tapping of it to detect any cavities, and the determination of tensile adhesion data for the bond with the substrate.

Acceptance inspection: visual assessment of the coating

By the time of the guarantee inspection after around five years, short-term operational influencing factors will have affected the coating. The groundwater, for example, may well have risen above the level of the temporary seals. It is also possible that the sealing action of the temporary sealing provisions was not lasting. The coating must then also assure sealing against the contacting groundwater.

Ultimately, the service-life will be achieved during operation, as a result of long-term operating influencing factors. The time leading up to this point will be characterised by years of exposure to fluctuating groundwater table loads, for example, and/or (bio)chemical loads. Further condition surveys will now be implemented at regular intervals, and may ultimately again indicate a need for renovation, or even renewal.

In-situ analyses

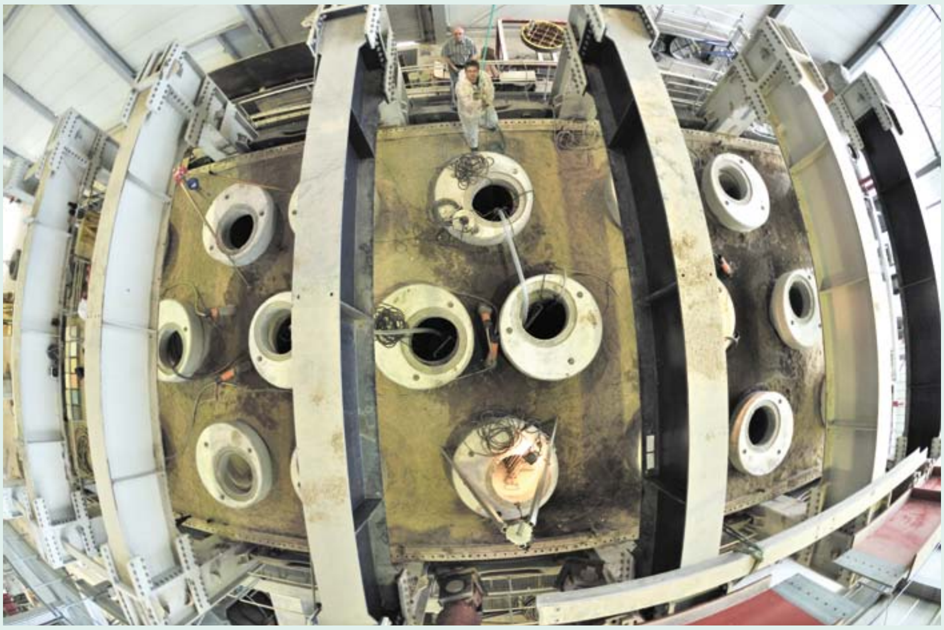
Twenty existing in-situ coatings ranging in age from around three to fourteen years were firstly examined in the context of the in-situ inspections, and also submitted to numerous quality tests, in order to determine the effects of years of exposure to operating loads.

In summary, the thirteen mortar coatings inspected demonstrated that satisfactory renovation results can be achieved even for an operating period of up to fourteen years. Careful preliminary sealing is necessary in the case of mortar coatings, in order that the hardening process is not impaired by any influx of groundwater. Uniform adhesion appears to be more important than only locally high tensile adhesion ratings. It was ultimately apparent that any damage had, predominantly, already been detectable as early as the acceptance inspection performed after one to six months. Further observations then served the purpose of assessment of the progress of the damage.

Significant deterioration was observed in five of the seven polymeric coatings inspected, on the other hand. The extent of cavities present immediately after coating constituted, in particular, a major problem in some cases, despite locally high tensile adhesion ratings. Uniformly good bonding appears to be of particularly great significance here. In view of the progress of the damage with time, special attention must be devoted to the guarantee inspection in the case of polymeric coatings.

Further on-site monitoring of sealing work performed on manhole structures and pipe-joint zones primarily served the purpose of selecting materials and procedures for subsequent large-scale and laboratory tests, and of obtaining orientation data for the boundary conditions of the large-scale tests. The conclusion of the renovation monitoring activities demonstrated clearly that sealing work on waste-water manholes necessitates a high time, labour and material input. In addition, the desired long-term success is not always achieved; the renovation task appears, in some cases, simply to be too demanding.

Monitoring of the construction of new manholes permitted the more detailed and profound recording of subsidiary construction costs and of follow-up costs, as the basis for a cost-effectiveness analysis of coating systems vs. new manholes.



Manholes in IKT's large-scale test facility

Installation of the manholes in the large-scale test facility

Large-scale (1:1) tests

The tests conducted at IKT's large-scale test facility investigated, in particular, the performance and robustness of the various methods under identical boundary conditions. The main focus was on variation of geometrical and process-engineering characteristics data and external loads, such as the formation of defects, for example, large-area fouling of manhole walls, and the level of groundwater tables as a function of the renovation conditions under examination. A total of twenty manhole structures consisting of prefabricated concrete elements were installed in a mixture of gravel and sand with a maximum particle size of 8 mm in the IKT large-scale test facility. The manholes had an internal diameter of 1000 mm (DN 1000) and a total structure height of around 5.6 m. Conduits and manhole linings of DN 300 were installed in the lower manhole sections. Stoneware and PVC-KG pipes were connected to the manhole linings installed.

Various geometrical faults were incorporated into the shaft rings and lower sections prior to and during installation of the prefabricated concrete elements. These simulated local and widespread leaks, and also leaking shaft ring joints, and took the form, essentially, of varying numbers of drilled holes of various sizes. A mould release agent for intentional weakening of the bond was applied to the "large-area leak" point of damage after completion of substrate preparation, but prior to coating.

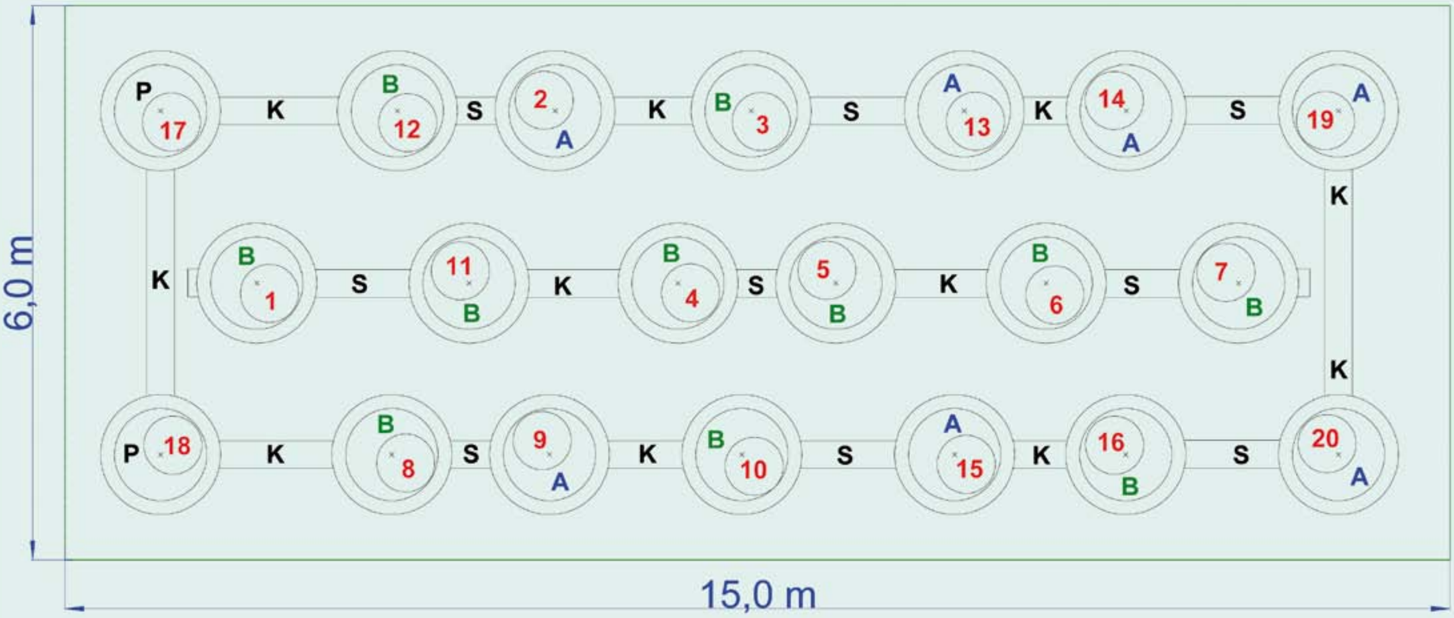
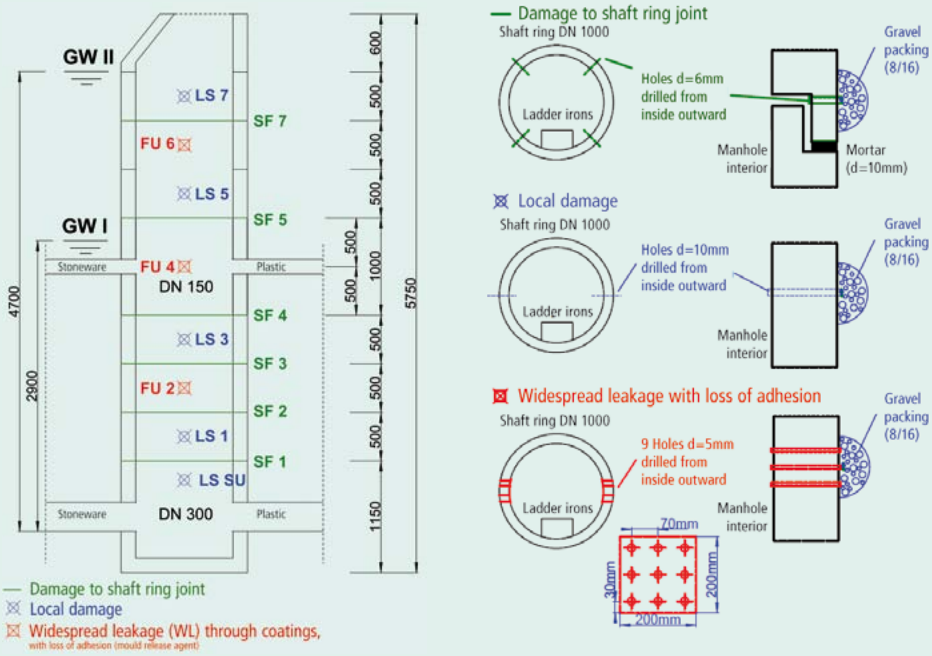


Diagram (plan view) of the manhole structure in the large-scale test facility
A: Manhole for sealing provisions; B: Manhole for coating provisions;
P: Pump shaft; K: PVC pipe; S: Stoneware pipe



Faults deliberately incorporated into manholes intended for coating: side view of the manhole structure (left) and damage patterns (right)

In addition to the geometrical damage to the manhole structures described above, the pipe joint zones intended for use of sealing methods were also deliberately damaged in advance. The seals in the pipe joint zones under observation were partially removed here.

The test procedure was characterised by the fact that the renovation operations customary on site - sealing, followed by coating - were separated from one another. In the case of the coating methods, this meant that the manholes prepared with defects (leaks) were firstly coated using various materials and systems but without prior sealing and with no groundwater in contact, and the water level only then raised. This water pressure then acted directly on the coating applied. A load such as this occurs in situ only in cases in which the prior sealing of the manhole structure fails or the groundwater rises above the sealed zones.

After curing of the coating materials, various methods and materials for sealing of the manhole structures and the in- and outlets were applied in other manholes, with influx of groundwater.

The coated manholes were visually inspected, and their condition documented, in parallel to this sealing work. The maximum groundwater table of 4.7 m above the lower pipe sole was maintained for a period of twenty weeks. The seals and coatings were inspected at regular intervals during this period; any changes in condition were documented, and any water ingress measured on a random-sample basis.
The procedure described above made it possible to apply the following time-compression effects, in order to accelerate possible failure of the renovated components:

Early application of maximum load to the component:
The maximum groundwater table was applied within a few days; a rise in groundwater can be anticipated in situ across a number of weeks or even months.

Early exposure of the renovation product:
Since coating was performed in dry state, with no prior sealing, the coatings were directly exposed to the contacting groundwater when the test facility was filled. The period normally required up to failure of a preliminary sealing and/or up to the rise in the groundwater table above sealing height was thus eliminated.

Foreshortening of exposure to maximum load:
The maximum groundwater table was applied in the test period for twenty weeks. In situ, it is generally necessary to anticipate fluctuating groundwater tables, with the result that a comparable exposure time and loading on the renovation product can be expected only across longer observation periods.

Continuous load-exposure / creep effects:
Plastics, in particular, exhibit significant creep when exposed to continuous load. Fluctuating groundwater tables in situ result in repeated relief and reversal of creep effects, whereas it was possible in the test to achieve comparatively continuous load scenarios, with corresponding creep phenomena.

At the end of the observation period, the water was drained from the test facility, and tensile adhesion tests performed on the coatings. Exposure of the manhole components also made it possible to inspect from the outside the injection bodies created during the sealing operations.

Polyurethane injection body on the exterior of a manhole

Results

An overall view of the project results makes it possible to summarise a number of basic perceptions which can be used by the system operators as a guide for further decision-making and action. These apply to the complete procedure, from the tendering and award-of-contract phase, up to and including acceptance of renovation work and supplementary Quality Assurance provisions.

Sealing suitable as a preparatory measure
➔ but long-term effectiveness remains dubious

Under exposure to external water pressure for a number of days in the large-scale test, resins and gels achieved good sealing of the damaged manholes. They are, therefore, also suitable as a preparatory measure for coating. Virtually all the resins and gels exhibited significant leaks after more prolonged exposure to external water pressure (around five months). Cementitious waterproof plugging compounds, on the other hand, exhibited a significantly poorer sealing action, even in the short term; their use is recommendable primarily for initial sealing of severe influxes of water, by way of preparation, for example, for more extensive injection sealing. Injection of a cement paste involved fundamental difficulties, due to the comparatively slight cavity/pore size of the well compacted surrounding gravel/sand soil used in the test.

Sealing of smaller-diameter (DN 150) pipe joints proved to be poorly reliable, even where resins/gels were used. The reasons can probably be found in the geometry of the manhole linings to be refurbished. The annular cavities for injection are significantly smaller in these instances than in the case of larger pipe joints (DN 300), with the result that the injection packers cannot be applied directly into the annular space, but must, instead, be applied into the manhole wall. The number and positioning of the packers may need to be matched to this circumstance.

The surface use of a crystallising mortar for sealing of the manhole structure achieved a special ranking. Specific applications have here not yet been clarified. The sealing action in the test was supported, but no contribution to load-bearing capacity or protective action (corrosion) was apparent. The extent to which this material's surface conditions (particulate, loose) can be improved by means of further provisions to make a protective action or improvement of load-bearing capacity possible by means, for example, of further coating with other materials, also remains open.

Mortars are durable, but frequently exhibited visual defects
➔ scarcely any risk of infiltration, even in case of bonding defects and shrinkage cracking

Cracking and moisture stains on the manhole wall, but no leaks involving measurable influx of water, were apparent in around 50 percent of the mineral coating systems. This also applied to those points at which the bond had been deliberately weakened using release solvents. IKT applied the mould release agent at these points prior to coating, in order to obtain initial indications concerning the "robustness" of the repair system vis-à-vis unexpected bond weaknesses, such as can occur in practice in case of lack of substrate pre-treatment. No wall breakage as a result of external water pressure was observed. This fact was attributed largely to the geometrical conditions, i.e., the large wall thickness (and thus stiffness), and the stabilising circular geometry of the coating. In interaction with the existing manhole, the external water pressure is then transmitted via compressive stresses in the mineral coating.

In-situ observations of mineral coatings of an average age of five to six years indicated that no infiltration-relevant deterioration of overall condition, and no perceptible corrosion damage, occurred during this period. The main focus of acceptance inspection should therefore be on the actual official acceptance inspection, with detailed documentation of possible conspicuous abnormalities. A check should then be made at the guarantee acceptance inspection to determine whether further spreading of any existing cavities and cracks can be excluded or not.

Random-sampling-based laboratory tests did not indicate any benefits from the use of repair products. Cases in which sealing of the surface prevents necessary water influx may be considered critical.

Plastic highly promising, with great demands on technology and execution
➔ only enduringly tight if preparation good

Polymeric coatings achieved good results, provided substrate quality was satisfactory, and execution careful. Punctiform damage, e.g. pinholes, occurred here only in the case of isolated products. These are irregularities of the size of a pinhead in the coating, and may also cause leaks. Blisters occurred in some cases as a result of external water pressure, where the bond had been deliberately weakened for the test, however. In a number of cases, these blisters spread to such an extent that they also impinged on areas of high tensile adhesion ratings.

All in all, polymeric coatings achieve a good coating result with high demands made on the technology used and the care exercised in application. More intensive study of these coatings during the guarantee acceptance inspection is recommendable, due to the great dependence of any faults on time, as was also observed in situ.

Full-surface bonding decisive for quality
➔ tensile adhesion data provide only additional safety

Full-surface bonding is more important than high tensile adhesion ratings in specific areas, particularly in the case of polymeric coatings. Even values of greater than 1.5 N/mm² do not provide protection against the spread of any blisters/detached points already present. No faults were observed where bonding was full-surface.

The mineral coatings investigated in the 1:1 scale laboratory tests exhibited average tensile adhesion ratings in the 0.5 to 1.3 N/mm² range, on the other hand. More intensive cracking and moisture stains were, it is true, observed for comparatively low values, but with only slight effects on sealing action, even at cavities.

Infiltration risk: seepage at ladder irons

Seepage at ladder irons is a significant weak point, with perceptible risks of infiltration, in both mineral and polymeric coatings. It should, in principle, be determined whether ladder irons or step irons can be removed, and replaced by means of suitable internals (ladders) in the context of coating projects.

Method selection determined by renovation target

The renovation targets determine method selection; it is necessary here to decide the extent to which the renovation project is intended to contribute to load-bearing capacity, to protective action and/or to the sealing action across the targeted service-life.

To restore load-bearing capacity, the material used must be capable of making good an advanced loss of structural fabric. High tensile adhesion ratings with the substrate illustrate, in the case of mortars, for example, the extent to which new and old material can be regarded as a joint load-bearing system. A protective action by the material may be required in the form of corrosion protection against the fluid conveyed in the drain/sewer system, with the result that material resistance must then be measured by this standard. It is necessary, with respect to sealing action, to differentiate between the effectiveness of the overall structure vis-à-vis internal pressure and vis-à-vis external groundwater pressure. In terms of robustness, the question arises, in particular, of the resistance of the above-mentioned load-bearing, protective and sealing actions under exposure to mechanical, biological and/or chemical attack.

It thus becomes apparent that the renovation target and the specific requirement profile for each and every coating project must be individually defined, and that it may decisively influence method selection. The use of mineral coatings may thus be a solution for making good loss of structural fabric under exposure to groundwater pressure, with no further danger of corrosion. Polymeric coatings, on the other hand, exhibit their best performance in the presence, for example, of aggressive fluids and where there are high demands for sealing against internal pressure. A combination of mineral and polymeric coatings may therefore constitute a technically rational solution in specific cases.

Preparatory work depends on manhole condition

The use of coating methods generally presupposes a clean and largely dry substrate capable across its entire area of bearing loads. The preparatory work then necessary will depend primarily on the condition of the manhole structure and only secondarily on the coating material to be used. Fouling must, for instance, always be removed, using high-pressure jets of hot water (for removal of grease and loose particles), for example. Where corrosion has occurred, the damaged substrate must under all circumstances be removed, by means of ultra-high-pressure or solids blasting (for roughening of the remaining surface and exposure of the particulate structure). Where infiltration has occurred, the structure must in all cases be sealed, by means of injection, for example, prior to coating.

Renovation record the precondition for acceptance

A comprehensive renovation record is the precondition for any official acceptance inspection. This documentation should be taken into account as early as the tendering stage, and should include the entire refurbishing process, from condition surveying, via sealing provisions, substrate preparation, coating and after-treatment, up to and including acceptance inspection of the renovation project. The quality requirements resulting from the renovation targets should be noted for orientation purposes. The location and scope of any damage to be repaired, and the preparatory work performed in the manhole structure, should then, in particular, be recorded, as the basis for subsequent checking of any weak points. The times for the official acceptance inspection and guarantee acceptance inspection should be scheduled as a function of the particular method selected.

"Manhole renovation" training programme

A training programme intended to contribute to the improvement of quality and enhancement of efficiency of manhole renovation projects has been developed on the basis of the research results examined above. The scientific contents are augmented by the up-to-date practical experience of the system operators and the IKT test facilities. Contents are orientated around practical implementation of notes for planning and recommendations for manhole renovation. The methodological instruments for inculcation of the taught material take the form of exhibits from the research project, specimen renovation projects, talks with and by experts, technical papers and workgroups.

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IKT - Institute for Underground Infrastructure

ABOUT IKT

IKT - Institute for Underground Infrastructure is a research, consultancy and testing institute specialized in the field of sewers. It is neutral and independent and operates on a non-profit basis. It is oriented towards practical applications and works on issues surrounding underground pipe construction. Its key focus is centred on sewage systems. IKT provides scientifically backed analysis and advice.

IKT has been established in 1994 as a spin-off from Bochum University, Germany.

The initial funding for setting up the institute has been provided by the Ministry for the Environment of the State of North-Rhine Westphalia, Germany's largest federal state.

However, IKT is not owned by the Government. Its owners are two associations which are again non-profit organizations of their own:

a) IKT-Association of Network Operators:
Members are more than 120 cities, among them Berlin, Hamburg, Cologne and London (Thames Water). They hold together 66.6% of IKT.

b) IKT-Association of Industry and Service:
Members are more than 60 companies. They hold together 33.3% of IKT.

You can find information on projects and services at:
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IKT is located ca. 30 min. off Düsseldorf International Airport.

Published: May 2012
Circulation: 3.000 copies

Protective charge: 19,95 €