The Collapse of the Header

beneath Trojska street, Prague

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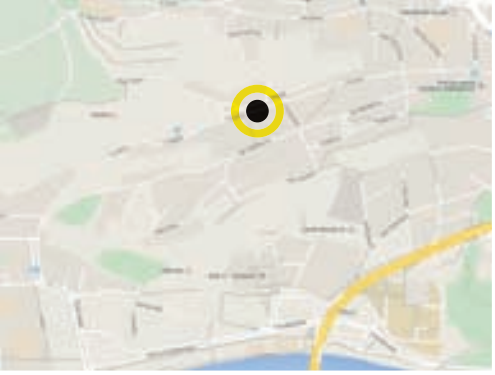

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The History

In 1939, the construction of the first part of the Trojský header was completed. Subsequently 695 metres of an oval-shaped sewer of Prague Normal (PN) dimensions 100/175 cm and 236 metres of a sewer of 80/144 cm dimensions connecting to the main E sewer was constructed beneath Trojská Street.

The next stage of the construction of headers in the Trojská Street area took place between 1972 and1975. At that time, there was a need to upgrade the capacity of the headers because of the planned construction of multi-storey, high-rise, prefabricated buildings in the Kobylisy area. The preliminary geological survey, however, foresaw very difficult conditions for its implementation, caused among others, by the depth of the sewer being 4-6 m and in some places even up to 12 m.

In October 1971, the competent building authority issued a permit for the construction of the waterworks and subsequently its construction commenced in March 1972. The actual conditions that were encountered during the construction exceeded the most pessimistic expectations. Despite the fact that recessing the route enabled avoiding contact with the saturated alluvial sediments, the enormous inflow of groundwater into the tunnel not only caused the work to be difficult, but also had a significant impact by seriously affecting the stability of the rocks and increasing the pressure on the lining. In some sections the excavation, in terms of its direction, was adapted to the local conditions, regardless of the project's priorities. It is understandable that under these conditions considerable overbreaks were created that probably were not always subsequently filled, thereby preventing the implementation of a solid contact between the lining and the rock. By October 1975, cca. 1.9 kilometres of the sewers had been constructed, comprising, in terms of dimensions, primarily sewer PN 100/175 cm with a length of 1.215 m and a 120/200 cm sewer with a length of 364 m. The construction works also involved creating 33 manholes, 27 of which were in brick sewers. 54% of the length of the newly built Trojský header has a gradient of between 2.2% and 5%, while 27% of the route's length has a gradient of between 5% and 6.5% and the remaining 11% reaches extreme values of between 9.1% and 9.8%. In the lowest part of the header the designed rainwater flowrate amounted to 10,404 m3/sec.

In terms of its manner of construction the header was built as a brick sewer, using conventional sewerage bricks, for the base and structured utilising circular earthenware segments; the Prague frame method was used for carrying out the excavation.

The construction was approved in June 1976 and subsequently put into operation. The fact is that the planned construction of the Trojská exit road did not take place and therefore the largest part of the header, including the manholes, had to be located on difficult-to-access private land. This was the main reason for checking of the condition of the construction being carried out only sporadically, in addition to its difficulty given by the slope and flowrate.

The Collapse of the Trojský Header

The process of the collapse of an entire section of the header evolved over a very short period at the beginning of July 1996. In late June, sewerage bricks were found in the Trojská rainwater separator during its regular inspection. However, the subsequent high level of rainfall prevented any inspection of the header and this was probably one of the causes of its collapse, which was unprecedented in the Prague sewerage network. The first evident manifestation of the accident was both very dramatic and rapid. On the 4th of July 1996, close to a tram stop, cca. 20 metres from the tram track, a funnel sinkhole appeared, with a diameter of cca. 16 m at ground level and a depth of 12 m, at the bottom of which wastewater was flowing. The sewer construction was completely destroyed and washed away. Directly connected to this sinkhole (hereafter referred to as P1) was a downstream cavern with a length of about 10 m and a height of cca. 3 m.

Regardless of which, the external manifestation of the accident continued. On the 14th of July 1996 a pass in overburden of the sewer resulted in the creation of circular sinkhole (P2) with a diameter of 2.5 m in the garden adjacent to the family house No. 256. This downthrow was closely linked to the collapse of the entire lateral part of the sewer.

Detailed exploration of the header, using the most up-to-date geotechnical reconnaissance methods, continued to obtain the most detailed information not only in regard to the actual extent of damage to the header, but also to the status of the rock mass behind the extrados.

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The result of the survey clearly confirmed the correctness of this procedure, since it identified the existence of additional caverns behind the extrados that till then had not manifested either in the flow-profile of the header nor on the surface, but which, if left unnoticed, would be a potential source of additional failure of the header, together with all its accompanying surface phenomena.
To determine the extent of the actual damage to the sewer an inspection of the entire sewer in Trojská Street was carried out in several stages, including photographic documentation and the surveying of the caverns. This survey, which was carried out in unstable caverns and under very difficult conditions, nevertheless provided sufficient basic information concerning the status, the geological condition, the degree of stability and the other parameters requisite for the project engineer to design a method for implementing the stabilisation of the rock mass and its timing. The results of these surveys were discussed with Prof. Ing. J. Barták, DrSc. from the Faculty of Civil Engineering of the CTU, who had also directly participated in the inspection and in the assessment of the stability of the individual caverns.

Project Documentation

Immediately after the accident had occurred and subsequent to the first local investigation, a design and engineering firm was selected, namely Ingutis s.r.o., for the preparation of the requisite project documentation, both in regard to the sanitation work and the final resolution. The selection of this specific company was implemented particularly with regard to its extensive experience in the designing of many important underground engineering projects in the Capital City of Prague.
The subsequent processing of the project documentation took into account the varying degrees of damage to the header; from the complete absence of certain sections of the header to the partial wear of the brickwork of its upper sections. The investor's and the operator's input conditions for the preparation of the project documentation were challenging, as they required:

- limiting the hydraulic capacity to the least extent possible
- designing the bottom part of the header so that it will resist the effects of abrasion and of high flow rates on a long term basis
- achieving perfect contact between the extrados of the sewer and the rock
- minimising construction costs
- implementing the construction within a period of two years

Preferred when choosing the building materials were:

- structural elements made of cast basalt, which the operator had tested practically in other construction projects regarding its suitability for sewerage. The use of oval-shape profile gutters of Prague Normal (PN) dimensions that have the advantageous adhesion of their reverse side to selected concrete mixtures, thereby significantly reducing the number and the length of the joints needed in comparison with using brick masonry and especially their excellent abrasion resistance, represented a key premise for the implementation of repairs and of the reconstruction of the header in its original route and in the existing vertical alignment.
- high-quality sewerage bricks for the arch of the header
- easily-processed concrete mixtures with the prescribed compactness and grain-size, which provided perfect performance, especially in regard to the bottom part of the header.

The project engineer proposed four basic technologies for the sanitation of the header:
(a) In the extensively damaged sections, and in those sections in which the sewer construction was complete destroyed, to implement the excavation of the sewer along its original route, together with the removal of the remaining structure of the header and to follow this by constructing a completely new structure. To install cast basalt gutter segments in the bottom part and subsequently, on the sides of the sewer, to follow this up by installing interlocking side panels, also made from cast basalt. Despite the satisfactory adherence of the basalt to the concrete, it was suggested that they could be anchored to the surrounding concrete by means of anchor bolts. The remaining part of the structure was designed in the manner of a traditional brick sewer.
(b) In those sections in which it was mostly only the bottom part of the header that was damaged, the project proposed the demolition of the entire bottom part of the header, underpinning the existing masonry and the installation of an entirely new bottom part for the header, again utilising basalt gutters and side panels. The perfect filling of the gap between the basalt elements and the rock with a concrete mix of the prescribed compactness and grain-size represents a critical premise for the success of the proposed technology.

(c) The section of the header with the 100/175 cm flow profile and the highest gradient between 5 and 98% were designed to be sanitised by using the sewer-in-sewer technology. This consists of lining the existing sewer with cast-basalt gutters and segments that are interlocked across the entire flow profile. The space between the basalt elements and the existing construction of the sewer was designed to be filled with poured concrete and in the roof part with shotcrete. Although this technology decreases the flow profile, it was suggested based on its satisfactory assessment in regard to the hydraulics. It should be noted, however, that on the basis of the detailed height and directional surveying of the original header, this proposed technology is currently being reviewed, since the large number of different shapes of basalt elements that will need to be installed, due to the identified directional arcs of the header, would prohibitively complicate this technology.
(d) The upper sections of the header that manifest either just normal wear and tear or minor defects were designed to be repaired. After milling the joints this involved the rejointing of the brickwork and replacing the damaged stoneware gutters in the bottom part of the sewer.

The Actual Implementation of the Construction

For the installation of the 595 mm deep basalt gutter that has a width of 888 mm, and subsequently of the 380 mm high basalt side panels, it was first necessary to proceed with the demolition of the brickwork and of the surrounding concrete infill, including the concrete base slab and also the drainage. The progress of the work in short sections and in units of metres appeared to be unacceptable, both because of the frequent alternating of the working operations with the transporting of small quantities of the concrete mixture and in terms of the total time consumption necessitated for the entire construction. Proposed therefore, and also subsequently implemented was underpinning the preserved parts of the brickwork with 60/100 mm metal L profiles that were anchored, both to the remaining structure of the sewer and to the rock, by means of a bolt with a length of between 800 and 1000 mm. Only then, based on the protection of this underpinning, did the demolition work commence, in synch, however, with the concurrent installation of supporting vertical uprights constructed from Ø 40 mm steel pipes. The interval between the demolition work and the completion of a new drainage system with a concrete base slab in sub-sections was max. 24 hrs. Implemented subsequently was the installation of basalt bottom gutters into concrete, the assembly of basalt side panels into shouldered shaped cross-section of the sewer and the installation of the metal M-20 anchor bolts that secure the positioning of the basalt side panels and their adherence to the surrounding concrete. The final phase included the completion of the concreting as far as to the level of the upper edges of the side panels, dismantling the L profiles, and the completion of the remaining space using sewerage bricks.

Conclusion

In regard to the history of Prague's sewers the collapse of the Trojský header represented a unique event, both in terms of its wide scope, its significance and in regard to the technical and financial requirements for its remedying. The total costs associated with its sanitation, including the design and survey works, exceeded CZK 120 million.
The mechanics of the initiation of the accident are not entirely clear. Most likely it was either a tensile failure of the brick sewer due to internal tension or to forcible erosion in places of masonry with a locally poor quality that was suddenly released during torrential flows at the time of the accident. In either cases, however, undoubtedly contributing to the origination and the continuing course of this extremely extensive accident was the free space behind the extrados, caused either through a lack of support for the lining in the event of its damage due to overpressure or in the form of "pockets", enabling, after the initial damage to the lining, further destructive erosion.
After the formation of the first large cavern and the occurrence of the sinkhole, during which large volumes of material were suddenly transported into the sewer, potholes appeared both in the sides and in the bottom of the sewer, or the blockage pressurisation process is repeated with the subsequent rupturing of the structure and the creation of the cavern, while the transporting of the washed-up rocks from faults in the higher sections of the sewer considerably accelerated the progress of this destruction.

There are other factors also, however, that might have contributed to the accident to a greater or lesser extent:

- The situational routing of the header, in accordance with the urban planning documentation, irrespective of the existing, very unfavourable local geological and hydrogeological conditions, which, however, were highlighted in the geological survey.
- The altitude progress of the route corresponding to the terrain morphology and the resultant enabling of high flowrates.
- The use of common building materials that had proved satisfactory during the standard conditions in Prague's sewer system but did not meet/match the extreme flowrate conditions. Using the common technology of excavation and of temporary fastening of the underground works, together with leaving wooden stringers in the tunnel after lining the sewer.
- The inconsistent filling of overbreaks that inevitably emerge in the given conditions.
- Failure to use the possibility of linking the parallel original header with the new header for the needs of revisions, which actually pre-restricted the possibility of its risk-free implementation

Since during the next two years smaller, but similar, accidents with sinks and with the collapse of the sewer occurred in Prague's sewer network, the origins of which are similar to those leading to the collapse of the Trojský header, the PKVT State Enterprise adopted the following measures and policies that it implemented gradually and intends henceforth to apply during the construction work taking place in Prague's sewer network:

During the project preparation and the construction of sewers of Prague Normal (PN) dimensions or their reconstruction special attention is paid to:

- the gradient and the flowrate conditions
- the choice of building materials with a preference for the basalt elements, for which the manufacturer Eutit s.r.o. and the PKVT State Enterprise processed the technical documentation, including the various dimensional categories of sewers
- all the measures implemented towards the implementation of the bottom part of the sewers that determine downthrows and release of the arch support
- the use of reinforcement for increasing the tensile strength of the arch in the event of pressure flow regimes

The following companies and organisations participated in the resolution of the accident:

- Ingutis s.r.o.
- Inset s.r.o
- Kankol s.r.o.
- ČVUT
- Eutit s.r.o.
- PKVT s.p.
- MHMP
- OBÚ Kladno

The Project Team:

- Prof. Ing. Jiří Barták, DrSc.
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