Prague underground tunnels crossing the Vlatava River

The project for the construction of tunnels as part of the new extension of Prague's Underground was faced with certain space limitations due to the location of an existing station. In addition, the particularly rough terrain in the area had considerable influence on the position of the planned station. At the place of crossing, the line is located at a depth of only one metre under the riverbed of the Vlatava. This minimal depth of the overlaying formation prevents the use of the tunnelling method, and therefore there remains only one "classical" method of construction – cofferdams. It was decided to use three cofferdams for the tunnel crossing situated in the Vlatava stream channel. This method is, however, very time-consuming and expensive, and would cause considerable hindrance to river transport, and even possibly damage to the works by flooding. Considering these facts, the general building contractor Metrostav Co. proposed an alternative approach – the so-called immersed tunnel launching.

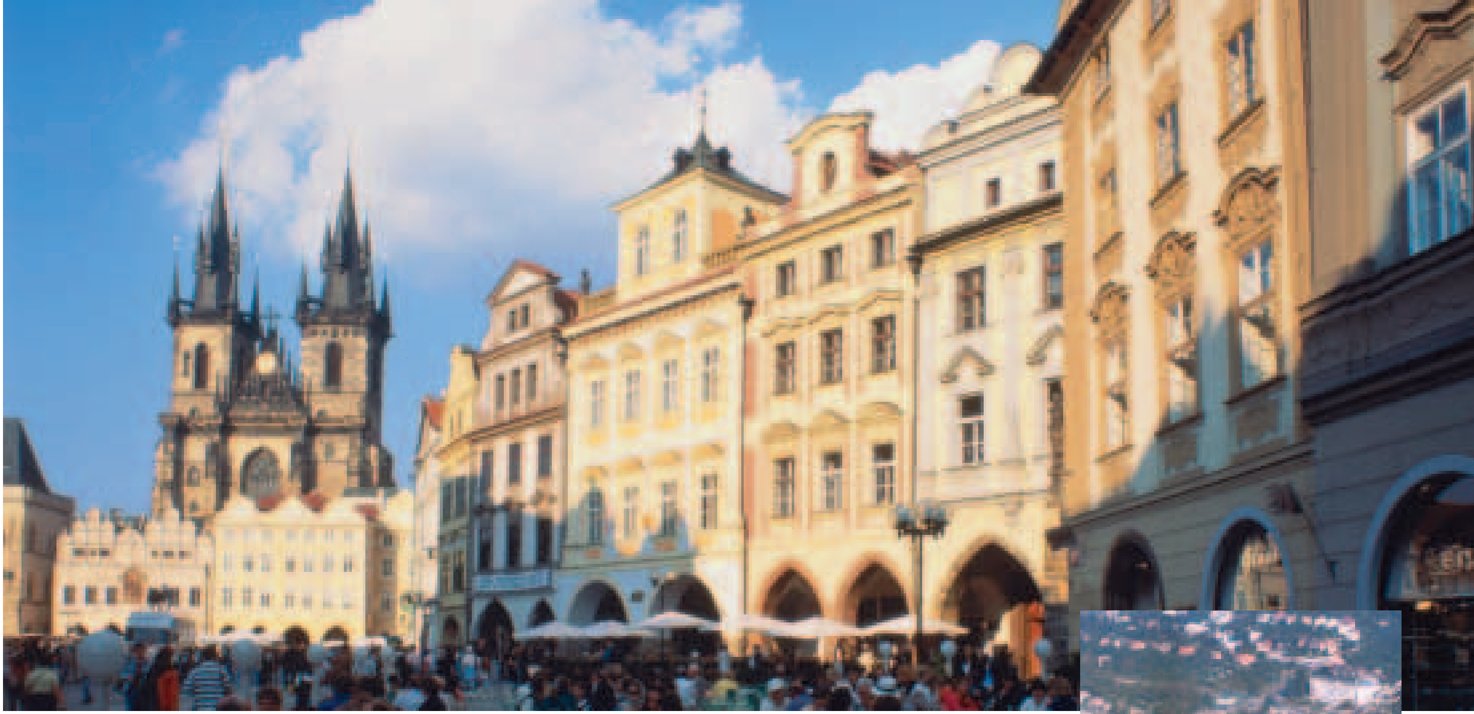
Panel for controlling the total stations TCRA 1101 X Range with graphic output of the readings and deviations of followed points from designed path.

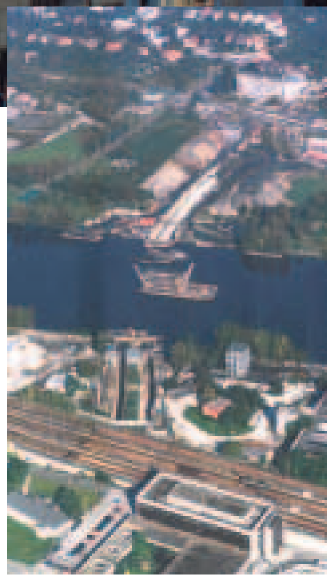
The principle of the immersed tunnel launching method
The Underground line under the Vlatava riverbed passes through two tunnels with horizontal and vertical curvatures. The basic principle of the technique consists of pre-casting the tunnels in an open pit – the "dry dock". On one bank of the river, this pit is separated from the river by means of steel sheet piling. In the riverbed, a channel is dredged, into which the tunnel body is launched. The tunnel body is closed by steel lids and after immersion it is balanced with the help of a system of interconnected water tanks, and placed within the tunnel allowing for selective flooding. Using two hydraulic stations on the opposite bank, the tunnel body is pulled and thereby launched. The third station is placed on the bank of the dry dock, and acts as a brake if necessary. The rear part of the tunnel is provided with steel skids and moves on concrete strips; lateral movement is limited by means of steel profiles. The front part of the tunnel body is suspended with cable slings from a pontoon, the height of which can be changed. When the launch is complete, the tunnel body is anchored to the concrete strips within the excavated channel in the riverbed.
The bottom of the tunnel is separated from the subsoil by means of textile bags, which are filled under pressure with concrete mix. The tunnel is additionally anchored with micropiles and the excavated soil is used for backfill.

Surveying work
Following the realisation of this method, great attention was paid to the surveying work, as the slightest inaccuracy of measurements would have an undesirable effect on the very principle of the technology. To minimize these undesirable influences, a micro-network was proposed in the area of the site, with permanent deep marking of points with forced centering. The surveying of the micro-network points was followed by the calculation of the three-dimensional coordinates of the points, which were invariable for the whole period of construction of the tunnel.

Surveying work during pre-casting of the tunnel in the "dry dock"
The surveying technology must secure the following:
- Staking out and survey of the three-dimensional position of the concrete soles;
- Survey of the three-dimensional position of the sliding formwork;
- Survey of as-built body of the underground tunnel;
- Calculation of the volume of the tunnel body and comparison with the design (special software was developed for this);
- Calculation of the mass of the tunnel body on the basis of the volume weight of samples of used concrete mix;
- Calculation of the volume of displaced water;
- Calculation of the coordinates of the centres of gravity of the segments;
- Determination of three-dimensional coordinates of the centers of reflection prisms mounted on steel structures in the front and central part of the tunnel body

Surveying work during the launching of the tunnel body
The basic requirement during the launch of the tunnel body was to create conditions for the conti-





Aerial picture of a dry dock with concreted tunnel:
(1) measuring and computer centre (2) station for centre independent control (3) construction ditch for fixing of the tunnel after transport.

nuous measurement and calculation of the three-dimensional coordinates of the points in the front and rear parts of the tunnel. It was also necessary to immediately evaluate deviations from the designed path; a difficult task especially when the bottom of the launched tunnel body was about 13 metres below the water level. The basis of the measuring system was two motorised total stations with a laser distance meter TCRA 1101 X RANGE connected on line to the computer and controlling system equipped with specially developed SW. During the monitoring and evaluation of the changes in the three-dimensional position of the launched tunnel, the influence of human factors was entirely eliminated. The measuring interval was set at 2 seconds, which at maximum displacement speed, represents an advance of two centimeters. The movement of the front part of the tunnel was independently followed and evaluated in the classical manner with a total station TCA 1102, and at the same time the transversal tilt of the tunnel was measured and evaluated.

During the launching, the number of measurements taken was
- 7907 in the front part of the tunnel
- 6668 in the rear part of the tunnel

The medium deviation of the followed point from the designed path was
- in the front part of the tunnel: P 0.012 m
- in the rear part of the tunnel: P 0.015 m

The final deviation of the tunnel axis (at the front of the tunnel) as against the design was P 0.004 m.

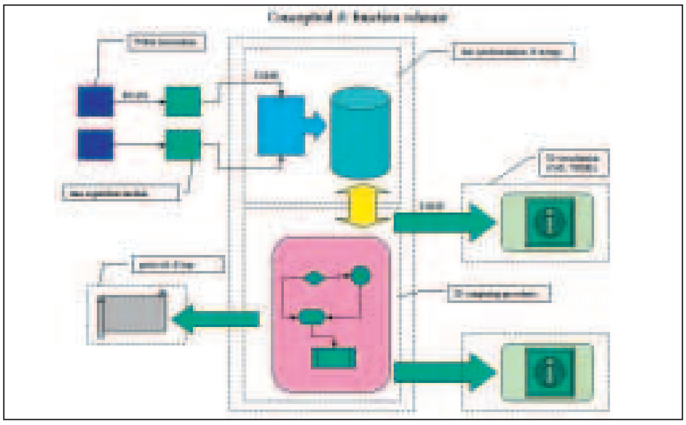


Diagram of the measuring and computing centre

Conclusion
The whole technological process of the construction of the tunnel and its launch into the desired position was undertaken without major problems, and accomplished with high quality. The proposed automated system of measuring and evaluating fully complied with the requirements established by the design, even though this unique technology was used for the first time in the world. Because the results of the measurements and evaluation were available on a continuous basis, it was possible to proceed and immediately correct the path and thus prevent the "oscillation" of the system. Justified praise goes to the total stations used, the TCRA 1101 X RANGE and TCA 1102, which contributed substantially to the successful accomplishment of the project, confirming their highly professional reputation. Following the success of this technology for tunnel construction and launch into the designed position, it will be used again without substantial changes in the construction of the second tunnel.

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Tunnel Facts:

Length of the tunnel:
168 m
Mass of the tunnel:
approx. 7 000 tonnes
External dimensions:
6.48 x 6.48 m
Thickness of walls:
730 mm
Thickness of top and bottom:
700 mm
Radius of horizontal curvature:
750 m
Radius of vertical curvature:
3800 m