Verification of the performance of the precast concrete lining in the Diabolo Tunnel and Liefkenshoek Rail Tunnel

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Summary

During construction of the Diabolo tunnel and the Liefkenshoek railway tunnel in Belgium, strains were monitored in several cross-sections of the precast concrete segmental lining. The obtained measurement data allow evaluating the in situ behaviour of the concrete lining under numerous loading conditions during and after tunnel drive works. The gradual development of strains in the initial stage after ring erection is discussed in relation to the grout loading, hydraulic jack forces and transferred soil and water pressures. Measurement sections below the River Scheldt show that the water level variation, linked to the tides of the North Sea, is clearly depicted in the strain results as a half-daily fluctuation. Results show that despite rough site conditions, strain monitoring proves a useful verification of tunnel lining performance and an important addition to tunnel design practice.

Keywords: strain monitoring; tunnel; precast concrete segments; ovalisation.

1. Introduction

In recent years, several tunnelling projects have been launched in order to extend the Belgian railway network. Among them are the construction of an improved connection to Brussels Airport, known as the Diabolo project, and a new freight connection in the Port of Antwerp, called the Liefkenshoek Rail Link. Generally, during tunnel construction, monitoring is limited to ovalisation of the tunnel lining, where both cited projects also include long term strain monitoring in the precast concrete segments of various tunnel rings. After the first experiences with strain measurements and ovalisation measurements in the Diabolo tunnel, an improved monitoring program is pursued in the Liefkenshoek tunnel, which is the main focus of this paper.

2. Liefkenshoek Rail Link project and measurement set-up

The Liefkenshoek Rail Tunnel aims to directly connect the railway freight transport between the left and right bank of the River Scheldt in the Port of Antwerp by 2014. The major part of the 16,2 km long connection is the twin bored tunnel, shield driven below the River Scheldt and the Port Canal using the mixshield method. Two parallel single-track tunnels with a length of approximately 6 km were excavated with an internal diameter of 7,3 m. The tunnel alignment is mainly located in tertiary sands, with a maximum water pressure above the tunnel floor of about 40 m and a maximum soil overburden along the tunnel route which equals 33,6 m. The design had to take account of the presence of an immersed road tunnel established in the 1980s close to the new location. In addition, the existing Beveren tunnel crossing the Waasland Canal needs to be renovated at full length of 1,2 km, as it has never been used since it was constructed.

During construction of both tunnel tubes, sixteen cross-sections of the tunnel lining were equipped with 18 strain gauges each, distributed across the ring perimeter in circumferential direction. In order to measure the strains in the reinforcement bars, part of the strain gauges were embedded in the segments prior to concrete casting.

https://doi.org/10.2749/222137813806478981 Distributed by structurae

3. Results

Measurement results show a clear distinction between the various steps in the boring process and allow observing the gradual development of strains and corresponding stresses in the concrete segments. As the TBM is pushed away from the last installed ring by the hydraulic jacks, tail grout loading and soil and water pressures are transferred onto the tunnel segments. From the presented results, it may be presumed that the loads acting on the tunnel segments during construction have a substantial influence on the sectional forces occurring in the tunnel lining. Therefore construction loads such as the thrust force of the shield jacks, possible pressure caused by contact with the tail seals and the pressure of the tail grouting can be decisive in the design of the tunnel lining.

Furthermore it can be noticed that the segmental lining of the leading tunnel shaft experiences minor changes in strain state during passing of the second TBM. These observations demonstrate the achieved accuracy of the continuous strain monitoring program, as simultaneous ovalisation measurements using laser scanning did not notice significant alterations during this phase.

The construction of cross-passages and the opening of evacuation shafts have a clear influence on adjacent measurement sections. Large and sudden jumps can be observed in the strain development of the concrete tunnel segments due to the gradual opening of the tunnel shell. During construction of one of the evacuation shafts, an incident occurred where the tunnel sealing was breached and a large amount of mud entered the tunnel. With the help of the strain results of the measurement section nearby the faulty area, the safety of the tunnel worksite could be assured.

Finally, measurement sections below the River Scheldt show that the water level variation, linked to the tides of the North Sea, is clearly depicted in the strain results as a half-daily fluctuation. It can be noticed that high water levels naturally result in a larger uniform compression of the tunnel ring, while compression forces in the tunnel lining decrease at low tide. Although the stress changes in the reinforcement steel remain rather small, a very good resemblance is found between the monitored half-daily tidal response of the tunnel ring and the theoretically expected stress changes from analytical calculation.

Monitoring of the tunnel lining performance proves useful not only during various construction stages, but also after completion of tunnel works and during the service lifetime of the structure. With this in mind, the strain measurement program verifying the state of the tunnel lining was extended for an indefinite period of time.

4. Conclusion

Strain monitoring allows evaluating the in situ behaviour of the tunnel lining under numerous loading conditions during and after tunnel drive works. Design of the precast concrete tunnel lining should not focus exclusively to parameters of the surrounding soil, the groundwater situation or loads on the surface level. It should also study the effect of loads during ring erection, advance of the TBM and tail grouting, as obtained measurement results have shown that these construction parameters may constitute a dominant factor in the tunnel lining design. The assembly stage can therefore be decisive in the design of the tunnel lining. Results show that despite rough conditions on site, strain monitoring proves a useful verification of tunnel lining performance and an important addition to tunnel design practice. Further research will concentrate on the validation of the various theoretical models for tunnel design in comparison with the monitored in situ behaviour.

5. References

[1] BOXHEIMER S., and MIGNON J., "Half way of construction of the Liefkenshoek Rail Tunnel", *Tunnel*, Vol. 3/2011, 2011, pp. 41-48.

[2] MASHIMO H., ISHIMURA T. and MORIMOTO S., "Evaluation of construction loads for the design of shield tunnel segments through field measurements", *Proceedings of the World Tunnel Congress, Helsinki, Finland,* 2011, pp. 32-33.

[3] SCHOTTE K., DE BACKER H., NUTTENS T., DE WULF A. and VAN BOGAERT PH., "Monitoring strains in the Liefkenshoek railway tunnel", *Proceedings of the World Tunnel Congress, Helsinki, Finland,* 2011, pp. 254-255.