The deployment of engineering models and design methods divorced from the effect that mechanised shield tunnelling with tunnel boring machines (TBMs) has on concrete segmental linings (CSLs) can lead to either material waste or structural damage within the tunnel design life. Most research to date on CSL behaviour during construction neglects the sequential ring loading and TBM-lining transverse interactions, which this thesis proved to be key in the short and long term behaviour of CSLs and whose study is essential if the design and maintenance of CSL structures is ever to be optimised.

This thesis investigates the longitudinal and transverse behaviour of CSL structures simultaneously backfilled with bicomponent grouts (BGs) during tunnelling, and how this early response influences long term behaviour. The research work is drawn on three pillars that enable cross-validation of conclusions: analytical models, three-dimensional numerical simulations and the interpretation of the Crossrail's Thames tunnel (CTT) field data, which included distributed fibre optic strain (DFOS) data. A theoretical framework ranging from construction loading scenarios to the mechanisms underlying structural damage is described for the future development of limit state design methods. Analytical models of longitudinal behaviour are also proposed. The study of joint geometries, temporary spear bolts and DFOS sensing in CSL construction monitoring is included as ancillary research.

The solution developed for a sequential elastic rod subjected to a trilinear temperature profile and in shear interaction with the elastic ground predicts accurately the early tunnel pre-stressing relaxation caused by grout hardening, e.g. ≈50% in the CTT. The proposed sequential elastic beam model, which incorporates the effects of stage-varying net TBM moments, transverse loads and lining pressure gradients within the tunnel unsupported length, estimates satisfactorily the history of tunnel beam response during construction for a realistic expression of the lining stiffness. A potential damage assessment method for the early detection of tunnel sections prone to ring joint damage was proposed.

The TBM-lining transverse interaction determines the CSL ring behaviour at the early stages of tunnelling. The ring response resultant from this interaction is irrecoverable and contributes to the long term total deformations and internal forces; in tunnels excavated in grounds with $K_o \approx 1$, it becomes the major source of ring distortion. The main transverse actions are the sealing pressures, which are inversely related to the tail clearance, and the transverse load of oblique hydraulic jacks. When the non-bedded rings are eccentric with respect to the shield tail, the ring distortion increases the risk of cracking near the rear corners and spalling at the ram pad interspaces of constrained segments. The ring distortion is directly related to the pressure gradients, the unsupported length and the ring flexibility. When individual segments rotate outwards under the action of transverse ram loads, e.g. the outer springline segment during pronounced TBM steering around a horizontal curve, the localised action of the sealing pressures can result in longitudinal cracking at the intrados of the segment front.

This study represents a qualitative leap towards the optimisation of CSL design, shifting the attention of researchers and designers to TBM-lining transverse interactions as the most determinant factor of structural response during construction in CSLs simultaneously backfilled with BGs.