CHAPTER 10
STAGGERED TUNNEL LINING DESIGN IN SOFT GROUND

Siti Norafida Jusoh, Hisham Mohamad,
Aminaton Marto, and Rini Asnida Abdullah

10.1 INTRODUCTION

Design of tunnel lining is an imprecise art. The ground and groundwater loads acting on a tunnel are difficult to assess and vary widely along the tunnel length and its periphery. Segmental tunnel lining which was widely adopted for underground tunnels in soft ground for a long time increases the complexity of soil-structure interactions in tunnelling. Prefabricated linings were used to speed up the assembling process but segment and ring interactions themselves give effect to the overall structural behaviour. In addition, lining and ground interactions are arbitrary, especially on how the ground loads the lining and at the same time supports it. The action-reaction from both ground and structure interaction is very vast and tailored to the sites, therefore, the tunnel lining design is not well understood and is overlooked. It is rather to be approached as an iterative process, with a great deal of practicality, in order to gain an appreciation of how the ground and lining are likely to interact. In this chapter, the discussion will focus on the tunnel response induced by joint interactions and joint configurations for more certainty in overall tunnel lining design in soft soil.

10.2 TUNNEL DESIGN PHILOSOPHY

Tunnel involves a complex distribution of stress around the excavation and inter-relationship between loads and deflections when the lining is subjected during construction and the final state stresses in the structure/ground interaction state. Tunnel has a close relationship with soil/ground properties, preconstruction stress in soil and characteristic of the lining. As the construction of tunnel with shield permits some ground movement, it concurrently results in the redistribution of the initial stress in soil. Soil will deform due to the excavation process and limit its movement by the installed lining. In reality, the deformations and the bending moments of tunnel are controlled by the stress path to which ground is subjected. The direct approach of lining design is by taking soil loading, calculating the stresses generated in the structure and evaluating the bearing capacity for the applied loads. However, the drawback of this approach is that soil loading is not an action but a reaction (Bakker, 2003). The soft ground around the tunnel periphery could be weathered soil or soft soil. The differences in vertical and horizontal pressure will result in a non-uniform load around the circumference. The lining is mainly response to the soft ground, which produces stresses, deflection and moment flexural. Therefore, it is crucial to take into account the soft ground load in tunnel lining design because it is an everlasting load applied to a tunnel, lasting long for tunnel operation time. Engineers must make sure important factors such as initial soil stresses, the soil deformation induced due to the tunnel's construction and the tunnel lining deformations themselves are things that affect the tunnel's stability.

From the structural integrity point of view, it is very important to make sure to strike the balance between loads and structural reactions and to confirm the structural stability (Bakker, 2003). Lining resists an axial thrust based on the overburden and groundwater pressure at springline, plus bending stresses resulting from an arbitrary percentage distortion of the diameter of the ring. The redistribution of ground stress creates an effect which is known as arching. It will continue until a balance is achieved. The proper criterion for judging lining behaviour is not to adequate strength to resist bending stresses, but adequate ductility to conform to imposed deformations (Bickel et al., 1996). Distortional loading introduced bending moments in the lining; both negative and positive bending moments.

By taking benefit of soil-tunnel interactions, a tunnel has to be flexible to bear the distortion and flexural bending moment. Therefore, the introduction of inelastic rings, segmental tunnel lining and joints are important aspects of tunnel-integrated design construction.

A tunnel can consist of (1) Rib and laggings (steel wide flange section), (2) Unbolted precast concrete segments (usually consisting of four segments erected within the tail shield, also called 'complete the ring' where the gap is stabilised by means of steel properties and filled with fast-setting concrete/grout) or (3) Bolted or pinned which usually consists of six segment with the key that bolted circumferential (segment to segment) and longitudinal (ring to ring) and more complicated to design and construct.

Figure 10.1 presents the definition of tunnel lining that consists of 3 rings of tunnel, each ring has segments that are connected with bolts (bolt pocket and handle bolt can be seen in the respective figure). The key segment and counter segment lied side by side with the key segment usually will be the last segment to be installed in a ring and the counter segment is a specially designed segment with a tempered side to allow the key segment installation. One can also see in the same figure, connections join from ring (i.e. ring's joint in this figure is connected by dowels) are imposed to make sure tunnel is capable of resisting relatively high moments and are effectively flexible to counter movement from the soil surrounding (Figure 10.1). The effect of the joints on the internal forces and deformations should be taken into consideration in the design of the tunnel linings (Arnau & Molins, 2011; Do et al., 2013a; 2013b; Teachavorasinskun & Chub-uppakarn, 2010; Yanzhi et al., 2014). By having joints, a flexible lining could be achieved and this will allow for further distribution of stresses in the soil until soil reached its stability (results in more uniformly distributed earth loading). Blom et al. (1999)