THE DESIGN CONSIDERATIONS FOR THE SEGMENTAL LINING OF THE HSUEHSHAN TUNNEL

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ABSTRACT

The design for the precast concrete segmental lining of the Hsuehshan Tunnel aimed for fast installation, economy in material use, and fast production in the precast yard. To satisfy the aforementioned requirements, a non-bolted, non-watertight precast concrete segmental lining with welded wire fabric as reinforcement was designed. The lining was applied not only as the initial support but as the final lining to save on the overall project cost. To reduce the bending stress on the lining to a minimum level, the radial joints were designed to be non-staggered and a knuckle type was introduced as the radial joint for the main bore so as to provide flexibility in rotation relative to the surrounding rock. Each of the radial joints can freely rotate a certain amount until the assembled segmental rings deform to the pre-set allowance. The concrete of the segmental linings at each side of the radial joint will touch and the radial joints will then "close". The circumferential joints were designed as a tongue and groove type so as to control the misalignment of the assembled rings in a longitudinal direction. Meanwhile, a rotational locking key was designed to resist the torque from the cutting wheel of the TBM and prevent the newly assembled ring from rotating in case the TBM operated in auxiliary thrust mode when the side gripper failed to grab the surrounding poor ground. The stresses for the segmental lining rings were analyzed by analytical solutions and numerical methods. The stresses for a single piece of segment at fabrication and the transportation stage due to handling and stacking were also considered. The design philosophy will be discussed and reviewed in this article.

Keywords: segmental linings, design, structural analysis

INTRODUCTION

Rock supporting elements for a tunnel bored by a modern full face tunnel boring machine may include rock bolts, shotcrete, steel sets, and segmental linings. Tunneling through heavily jointed and blocky rock formations calls for the use of a fully shielded tunnel boring machine to protect the tunnel crew and equipment from being hurt or damaged by falling rock. To cope with the fast boring of a fully shielded tunnel boring machine and to provide a sound reaction for pushing the machine forward in blocky rock formations, segmental linings are the best choice among all the aforementioned rock supporting elements. Segmental linings can be installed quickly within the tail shield of a fully shielded tunnel boring machine so as to provide a continuously supported tunnel, avoiding any exposure of rock wedges on the tunnel crown and wall. The quality of the segmental lining is relatively easy to control because it is fabricated in a precast yard with a reliable standard procedure.

The disadvantage of the segmental linings is the material cost, however this can be offset by the savings on the time-related costs for tunnel boring and supporting. Therefore precast concrete segmental linings were chosen as the initial rock supports for the Hsuehshan Tunnel. This paper describes the goals for the designer to achieve, the skill for deciding the dimensions, and the analysis model which led to the success of supporting the tunnel.

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DESIGN GOAL

The main goal of the design was fast installation. The AEC (Asian Expressway Consultants, formed by a cooperation of well-known expatriate experts and local consultants) chose to go with a non-bolted support type which was obviously a modification of the linings of the Bozberg Tunnel in Switzerland. An investigating team dispatched to the Bozberg Tunnel was convinced that the lining system could be installed in 12 minutes after a certain learning period for the tunnel crew. A bolted system could never match this speed. Meanwhile, a sheet of fleece designed to be attached between the segmental lining and the cast-in-place concrete inner lining, serving as a water pressure release valve, excluded the necessity of joint gaskets which customarily accompany joint bolts. The secondary goal was a low cost lining.

To fulfill this requirement, the radial joint could not be staggered so that the rings would behave like a series of prayer beads in a plane strain state according to a previous study done by Chang and Wang, 1991. The radial joints act like pins. By doing this, the deformation of the ring comes from the rotation of the radial joint instead of the strain on the material of the segmental lining. Therefore, no bending stress will occur unless the joint rotates to its limitation. This would reduce the reinforcement required, while at the same time the deformation of the ring helps the surrounding rock release the rock pressure until a balance between rock load and support pressure is achieved.

CONFIGURATION OF THE SEGMENTAL LININGS

The segmental lining ring is composed of 6 pieces of segments including the keystone which is located at the bottom of the ring (see Fig. 1). The installation of a non-bolted ring needs special consideration especially for a huge ring weight of more than 10 tons. The two inverted pieces initially touch each other by their own weight. The two side wall pieces are put above the invert pieces and they also lay on the tail shield. They were carefully dimensioned so the center of gravity of the wall piece fell outside the contact point of the wall piece and the inverted piece at the initial stage of installation so they would not overturn even without a mechanical support facility. Then the installer places the crown piece into the crown position and it remains at that exact location. The inverted pieces are then jacked upward with the wall piece also going upward to give space to drop in the keystone. The wall pieces will be supported by a roller to prevent overturning. The assembled ring is pushed backward to lock with the previously installed rings. The ring is 10.4 meters in diameter with a thickness of 35 cm for the crown and wall pieces. The thickness of the inverted pieces increases gradually toward the bottom to form a flat walkway for the electrical gallery. The keystone is thinner than the inverted piece at the walkway location to form a drainage ditch. The circumferential joint is the tongue and groove type (see Fig. 2). It helps to lock the adjacent rings to avoid misalignment. The tongue and groove for the keystone takes a perpendicular direction (see Fig. 3). This is to avoid the rotation of the whole assembled ring by the reaction torque generated by the cutter head of the tunnel boring machine.

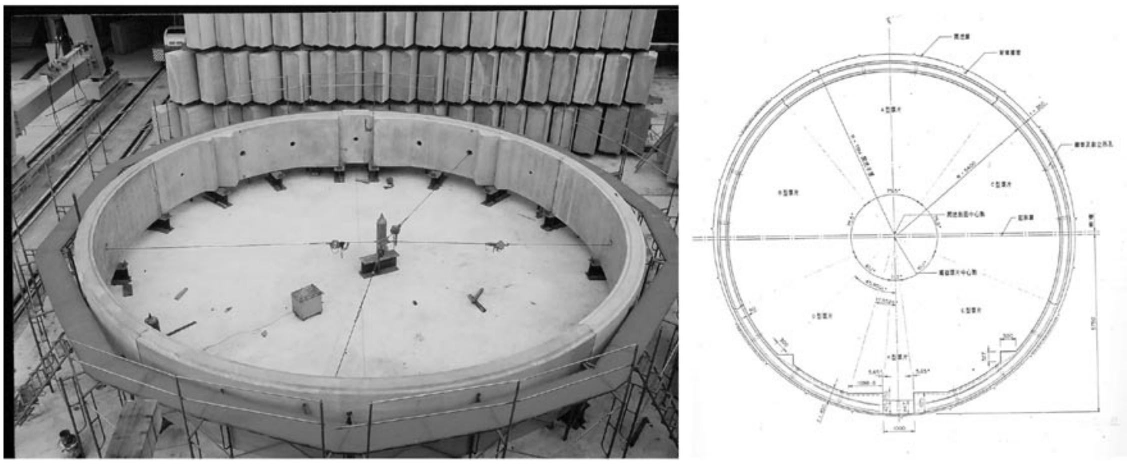


Fig.1 The Segmental Lining

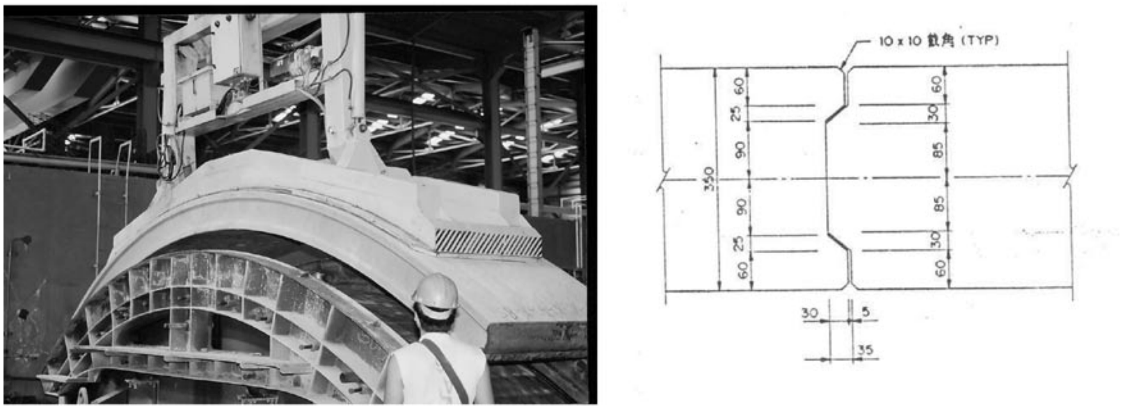


Fig. 2 The Tongue and Groove Type Circumferential Joint

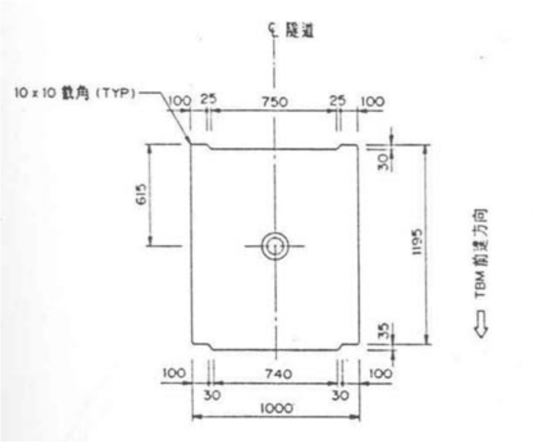


Fig. 3 The Keystone

STRUCTURAL ANALYSIS

Structural Model of the Ring

The radial joint is designed as a knuckle joint type as shown in Fig.4. It will be treated as a pin before it rotates by 3.3 degrees and the joint becomes a closed joint. After the joint closes it will be modeled as a rotational spring. (See Fig. 5) An iteration process has to be followed to get the spring constant of the joint. The flow chart for this process is shown in Fig. 6.

Estimation of the Pressure on the Lining

The pressure on the lining is determined by the initial stress of the ground, the stiffness of the ground, the strength of the ground, the distance from the cutting face to the backfill point, the amount of gap between the cutting diameter of the TBM and the tail shield, and the amount of gap between the tail shield and the segmental

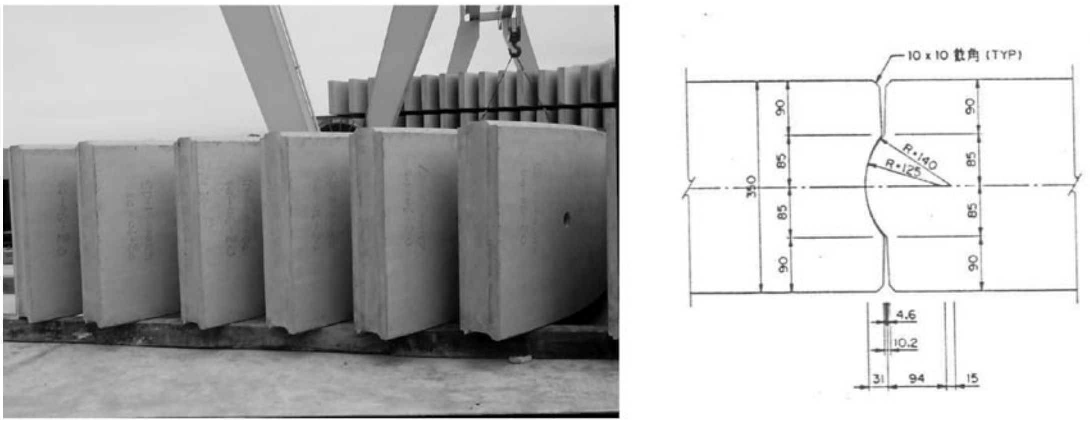


Fig. 4 The Knuckle Type Radial Joint

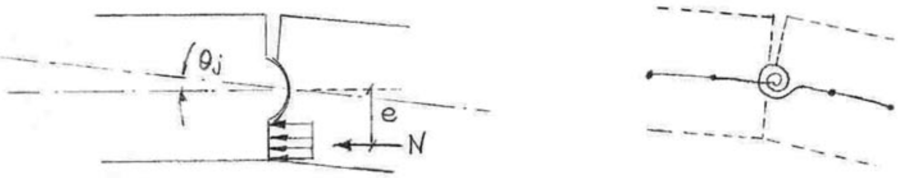


Fig. 5 Stress Distribution at the Radial Joint and the Rotational Spring Model

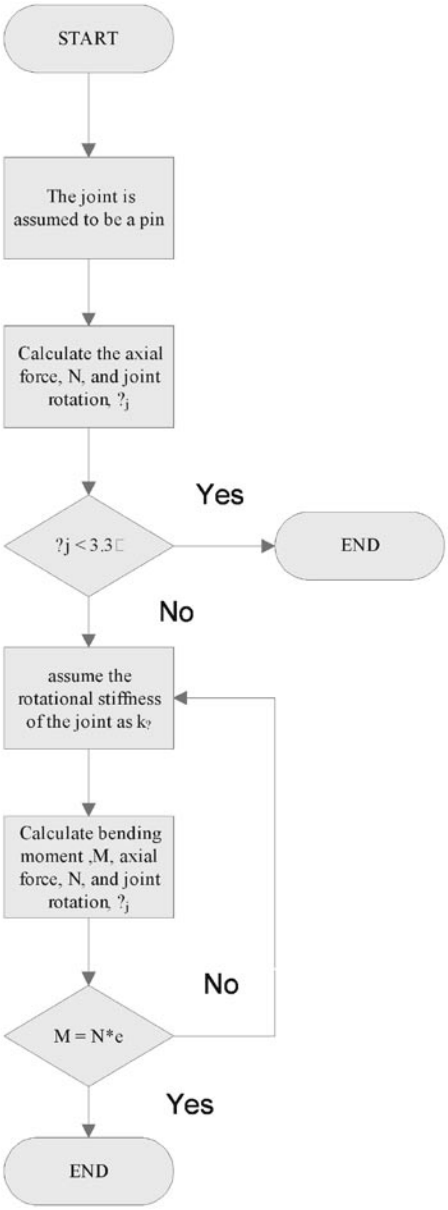
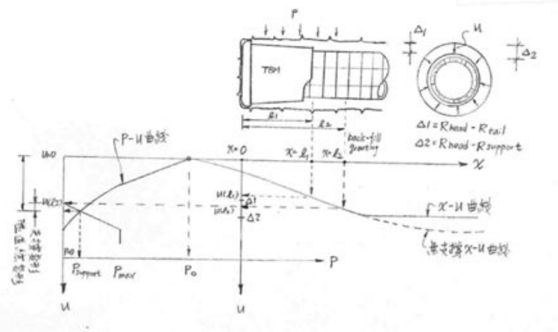
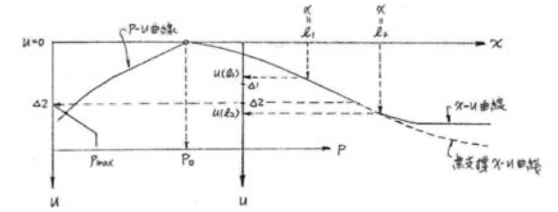


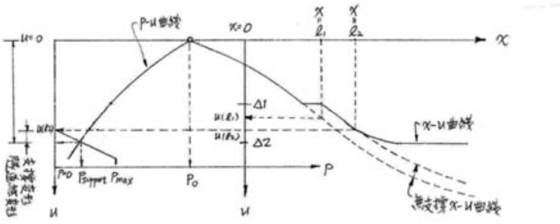
Fig. 6 Flow Chart Showing the Iteration Process for Determination of Joint Stiffness



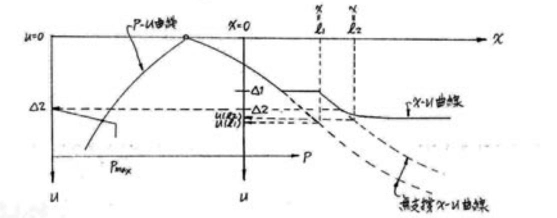
Case 1 u (l1) < 1, u (l2) < 2



Case 2 u (l1) < 1, u (l2) > 2



Case 3 u (l1) > 1, u (l2) < 2



Case 4 u (l1) > 1, u (l2) > 2

Fig. 7 3 Axis Schematic Drawings Showing the Relationship among the Rock Pressure, the Rock and Support Deformation, and the Distance from the TBM Cutting Face linings. A distance-pressure-deformation 3 axis drawing was used to determine the pressure on the lining.

Fig. 7 shows the four cases that may be encountered. They were explained as follows: Case 1 means that the unsupported deformation at shield tail is smaller than the taper of the TBM, and the deformation at backfill point is smaller than the tail void. Case 2 means that the unsupported deformation at the shield tail is smaller than the taper of the TBM, while the deformation at backfill point is larger than the tail void. In this case the contact between ground and lining will occur earlier than that of case 2. Case 3 means that the unsupported deformation at the shield tail is larger than the taper of the TBM, while the deformation at backfill point is smaller than the tail void. In this case the contact between ground and shield skin of the TBM will occur and because of the existence of the shield that it would be possible to install the lining inside the shield without encroachment of the ground. Case 4 means that the unsupported deformation at the shield tail is larger than the taper of the TBM, and the deformation at the backfill point is also larger than the tail void. In this case the ground encroaches into the tail void right after the segmental lining is pushed outside the shield. This would happen in extremely high overburden or adversely poor ground conditions or a combination of both. The pressure on the ring is high and a check on the clamping force of the shield must be done to investigate the necessity of the enlargement of the boring or if a pretreatment plan is required.

CONCLUSIONS

The knuckle type radial joint and the tongue and groove type circumferential joint without one single bolt for installation makes the assembly work neat and fast and the lining to be economical and safe. The concept of distance-pressure-deformation 3 axis drawings provides a clear picture on how to estimate the loads on the linings and also provides a method for evaluating the possibility of the jamming of the TBM.

REFERENCE

* Chang, C.T. and Wang, J.J. (1991), "A Breakthrough on Design of Segmental Tunnel Linings", Proceedings of the 9th Asian Regional Conference on Soil Mechanics and Foundation Engineering, Bangkok, pp.311-314.