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Automated construction of the Paghuashan tunnel for Taiwan High Speed Rail (THSR) project

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Abstract

The Taiwan High Speed Rail (THSR) project is the most significant infrastructure development in Taiwan, and the largest Build–Operate–Transfer (BOT) project in the world. The project is required to be completed and in operation as soon as possible. The THSR's longest main tunnel, at 7364 m long crossing Paghuashan hills, was considered as the most critical sub-phase of the project. To ensure effective control of this critical phase, the joint venture contractor brought highly efficient construction equipment and fresh planning ideas into Taiwan. The main tunnel's excavation work was carried out using a method minimizing harmful loosening of adjacent groundmass. Engineering records reveal that the Paghuashan project was implemented successfully. The project was completed two months ahead of schedule, and even recorded the best monthly excavated length of 250 m, marking a significant milestone in the progress of the THSR project. This paper introduces the cycle of excavating and lining technique used in constructing this key tunnel, and an the analysis of work productivity through the utilization of these automated equipment and facilities. This investigation also provides detailed insight and experience for future long tunnel construction, particularly in bidding for Design–Build (DB) contracts.

Keywords: Tunnel; Automation; Taiwan; BOT

1. Introduction

Taiwan has vast uninhabited mountainous regions. About 95% of the national population of 24 million live on the narrow strip of coast in the western part of the island. Conventional intercity transportation options cannot easily manage the increased traffic loads, resulting in service quality deterioration.

Considering the expected rapid growth in demand for intercity travel, and with Government officials looking to the example of Japan with its highly advanced system of dedicated high-speed routes linking major cities, which have famously transformed medium and long-distance travel between major population centers, the Taiwan High Speed Rail Project (THSR), emphasizing safety, mass transit, restricted land use, energy efficiency and minimal pollution, is expected to alleviate the overcrowding traffic, and improve the regional development balance significantly. The Taiwanese Government drew up a detailed proposal to construct a new 345-km route, capable of running trains up to 300 km/h between the island's north and south within a 90-min travel time. The THSR revolutionizes the concept of space afforded by its fast linking, making one-day commuting along the extensively developed west corridor a reality [5].

The shortage of public funds to finance new infrastructure projects has led the government to adopt the BOT infrastructure delivery approach, where the private sector finances, designs, builds, operates and maintains the facility for a stipulated period of time, then transfers it to the government. In July 1998 the concessionaire, Taiwan High Speed Rail Company, and the government, signed a 35-year concession agreement including a commitment to raise the cash to construct the line from private sources. Physical work on the project began in early 2000. Over 300 km of the line's total 345 km length was built either in tunnels or on viaducts, owing to the densely-populated

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corridor through which the system passes. The system is scheduled to commence commercial operation in late 2005. The THSR Project is the largest transportation infrastructure initiative in Taiwan, and the first major Taiwan national public facility involving private investment. The US$13 billion makes this project one of the largest construction projects of the late 20th century. The THSR project undoubtedly bears significant expectations, not only in terms of the socio-economic development in Taiwan, but also as a milestone of industrial technology initiatives. Therefore, the concessionaire and all consortia recognized the requirement to implement the project on time, within budget and to quality specifications. Delayed delivery of civil work of the THSR project will affect the progress of succeeding trackwork and core system integration, therefore the severe penalties are set to discourage time extensions.

In the preplanning phase of the THSR project, tunneling was quickly identified as a key sub-task. The project includes approximately 47 km of tunneling of which 39 km are mined and 8 km are Cut and Cover tunnels. Because of the high complexity and uncertainty in tunnel excavation, the major tunneling work of the 48 tunnels was placed on the critical path of civil construction scheduling. The longest main tunnel, 7364 m long, crossing the Paghuashan hills is considered as the most crucial mission in the critical path of the entire THSR project. To ensure effective management of this vital tunnel project, the joint venture between Bilfinger Berger AG of Germany and the local contractor Continental Engineering Corp. introduced many new characteristic and highly efficient automatic construction equipment and fresh planning ideas. The main tunnel excavation work was typically carried out using a backhoe tunnel excavator, minimizing harmful loosening of the adjacent groundmass. Data including engineering records demonstrate that the Paghuashan project was performed successfully. The upper half of tunnel section had an average excavation length of 133 m per month, and was completed two month earlier than scheduled. Further, the Paghuashan tunnel even recorded the best monthly excavated length of 250 m in the THSR project. This paper investigates and analyzes automation in excavation and construction of this critical tunnel, including general geological information, construction techniques, support measures, working productivity, equipment and facilities, management approach and the overall success, and helps provide detailed insight and experience for future long tunnel constructions, particularly for contracts with Design–Build under significant pressure to be completed on time.

2. Paghuashan tunnel project

The THSR project contains five major tunnels over 2 km long, of which the longest is the Paghuashan tunnel with mining over 7.3 km. The Paghuashan tunnel consists of a major twin-track tunnel with typical horseshoe-shaped cross-sections of 130 m^2 excavated faces and two emergency adit tunnels. The tunnel is aligned approximately north–south, and ranges in elevation with respect to sea level from 100 to around 154 m. The overburden varies from a few meters up to a maximum of approximately 90 m. The THSR alignment normally follows the most populated region along the western coast of the island, and therefore the tunnels do not cross mountain ranges with high overburden. Fig. 1 illustrates the alignment section layout with the elevation of the Paghuashan tunnel, and Fig. 2 shows its typical section geometry.

Most tunnels in Taiwan have been in either rocks or soil. Gravel formation encountered at the Paghuashan tunnel, which kept properties between rock and soil, is a rare occurrence in Taiwan [14,15]. To avoid the likely effect of groundwater on excavation, the level of the Paghuashan tunnel inverts were designed to be above the groundwater table by several meters, as shown in Fig. 1. The next section discusses geological conditions in detail.

3. General geological situation

The THSR enters the Paghuashan terrace from the north and leaves it in a southerly direction to enter the alluvial plains west of the Paghuashan Terrace. The Toukoshan Formation in the northern zone of the Paghuashan anticline, in which the

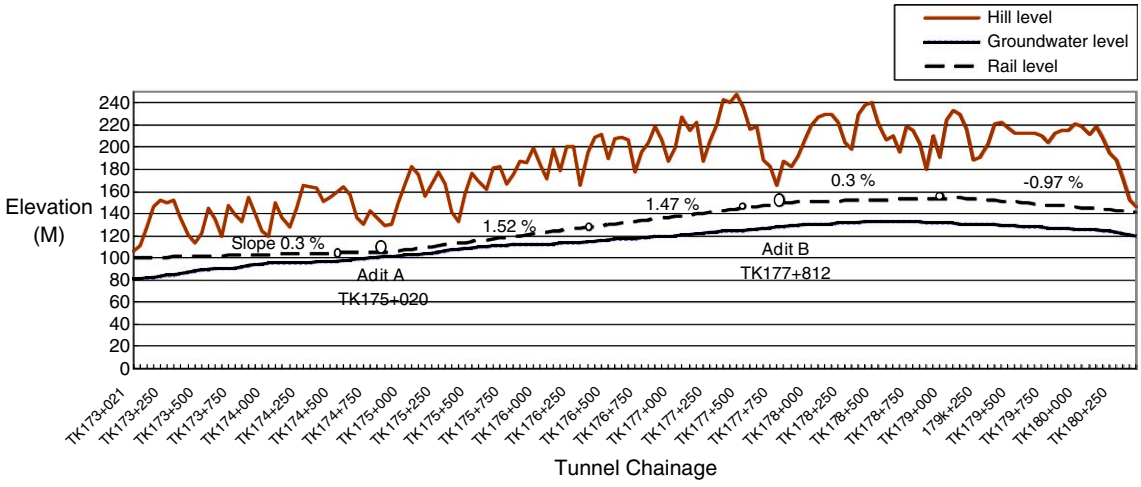

Fig. 1. Alignment layout of Paghuashan tunnel.