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Technical Note

# Double-O-Tube shield tunneling for Taoyuan International Airport Access MRT

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ABSTRACT

From 1989 to 2010, 20 tunneling projects have been carried out with the Double-O-Tube (DOT) shield tunneling method in the world. In this paper, the DOT shield tunneling for the construction of Taoyuan International Airport Access (TIAA) Mass Rapid Transit (MRT) system is introduced. A 6.42 m-diameter, 11.62 m-wide DOT shield machine was used to build the first DOT tunnel in Taiwan. Field data indicated that, throughout the tunneling operation, the rolling angle of the DOT shield varied between +0.23° and −0.39°, which was within the limiting design values of +0.6° and −0.6° proposed by both TIAA MRT and Shanghai Metro. For the six surface settlement troughs collected from Tokyo, Shanghai and Taipei, the ground loss due to DOT shield tunneling ranged from 0.23% to 1.30%, and the average ground loss was 0.78%. As compared with the ground loss due to single-circular Earth-Pressure-Balance (EPB) shield tunneling in cohesive soils, the range of ground loss due to DOT shield tunneling was relatively narrow, and the peak ground loss value was significantly less. Underground excavation with the DOT tunneling method would increase the tunneling duration for about 32%. The cost per meter of tunnel constructed with a DOT shield was about 1.5 times that constructed with single-circular shields. The cost of shield machine and segment lining were 23% and 53% of the total tunneling costs respectively. The expensive DOT shield machine and the complicated manufacturing and assembly of DOT lining segments are the main reasons for higher cost of tunneling. However, it would cost a lot more budget and it would be much more risky to excavate three cross-passages between the single-circular tunnels under the river.



## 1. Introduction

In recent years, due to the rapid development of urban areas, a lot of public facilities such as the Mass Rapid Transit (MRT) systems and underground sewerage systems have been constructed. Because of the disruptive effects of the cut-and-cover method, it has been becoming more popular to employ the shield tunneling method for passing under commercial areas with heavy traffic. The Double-O-Tube (DOT) shield tunneling has a minimized section area, and enables the most efficient use of underground space (Chow, 2006). As compared with circular twin-tube tunnels, the DOT shield tunnel may pass narrow underground corridors, and the impact on nearby structures is minimized (Sterling, 1992; Moriya, 2000).

From 1989 to 2010, as summarized in Table 1, 20 tunneling projects were constructed with DOT shield tunneling method. The first 13 cases were carried out in Japan, the next six cases were conducted in Shanghai, China, and the latest one was constructed in Taipei, Taiwan. The purposes of tunneling were to excavate subway tunnels, sewer mains, and common conduits. The formation of soil consisted of gravel, sand, silt, clay and peat. In Table 1, the diameter of DOT shields varied from 4.45 to 9.36 m, and the width of shields varied from 7.65 to 15.86 m. The length of tunnel ranged from 249 to 2497 m. The minimum radius of curvature of tunnel alignment was 102 m, and the maximum tunnel gradient was 5.9%. Table 1 indicated, all 20 DOT shields used up to 2010 were made by Japanese manufactures. It is obvious that Japanese play a leading role regarding the development of DOT shield tunneling technology. In Table 1, IHI represents Ishikawajima-Harima Heavy Industries, MHI represents Mitsubishi Heavy Industries, and KHI represents Kawasaki Heavy Industries.

In this paper, the DOT shield tunneling for the construction of Taoyuan International Airport Access (TIAA) MRT is introduced. This is the first DOT shield machine employed in Taiwan. The rolling angle of the DOT shield measured as a function of the ring number was presented and studied. Surface settlement troughs due to DOT shield tunneling in Japan, Shanghai and Taipei were collected and compared with those estimated with empirical methods.

Shen et al. (2009) stated that the disadvantages for a single-circular shield tunnel are resulted by high construction cost and long construction period. That is why the DOT shield tunneling method was proposed in Japan. However, from a practical point

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**Table 1**
Projects constructed with DOT shield tunneling method.

| Case no. | Project name | Purpose of tunnel | Geological condition | External dimensions of DOT shield (m) | Length of tunnel (m) | Thickness of overburden (m) | Minimum radius of curvature (m) | Maximum gradient (%) | DOT shield manufacture | Period of construction |
|---|---|---|---|---|---|---|---|---|---|---|
| 1 | Rijo tunnel, 54th national route Hiroshima, Japan | Subway | Clay, sand | ∅6.09 × W10.69 | 850 | 5.0–8.3 | 135 | 1.8 | IHI | 1989–1994 |
| 2 | Kikutagawa 2nd sewer main Narashino, Chiba, Japan | Sewer main | Fine sand, clay, peat | ∅4.45 × W7.65 | 703 | 2.15–9.0 | 1600 | 4.0 | IHI | 1990–1994 |
| 3 | Ariakekita common conduit Tokyo, Japan | Common conduit | Clay, gravel | ∅9.36 × W15.86 | 249 | 14.0–17.0 | 1600 | 3.5 | MHI | 1990–1994 |
| 4 | Underground line, coastline high speed transit, Kobe, Japan | Subway | Clay, gravel | ∅5.48 × W9.75 | 304 | 11.5–15.5 | 1500 | 0.8 | MHI | 1995–1998 |
| 5 | East district of Sunadahashi, 4th line high speed transit, Nagoya, Japan | Subway | Sandy gravel, silt, clay | ∅6.52 × W11.12 | 752 | 10.31–16.6 | 500 | 2.3 | IHI | 1999–2002 |
| 6 | Chayagasaka park district, 4th line, high speed transit, Nagoya, Japan | Subway | Silt, sand | ∅6.52 × W11.12 | 1007 | 11.0–32.1 | 500 | 3.3 | IHI | 1999–2002 |
| 7 | Yamamoto north district, 4th line, high speed transit, Nagoya, Japan | Subway | Clay, sand, sandy gravel | ∅6.52 × W11.12 | 1238 | 9.3–32.3 | 300 | 2.7 | IHI | 1999–2002 |
| 8 | South district of Nagoya University, 4th line, high speed transit, Nagoya, Japan | Subway | Clay, sandy silt, sandy gravel | ∅6.52 × W11.12 | 876 | 11.5–21.3 | 200 | 3.1 | IHI | 1999–2002 |
| 9 | Yagoto north district, 4th line, high speed transit, Nagoya, Japan | Subway | Clay, sandy gravel | ∅6.52 × W11.12 | 782 | 19.0–24.0 | 180 | 0.9 | KHI | 1999–2002 |
| 10 | Yamashitadori south district, 4th line, high speed transit, Nagoya, Japan | Subway | Sandy gravel | ∅6.52 × W11.12 | 957 | 10.0–16.6 | 165 | 3.3 | MHI | 1999–2003 |
| 11 | Yagoto south district 4th line, high speed transit, Nagoya, Japan | Subway | Clay, sandy gravel | ∅6.52 × W11.12 | 1025 | 16.2 | 300 | 3.1 | MHI | 1999–2003 |
| 12 | East-terrain line, 1st district, Aichi, Japan | Subway | Sandy soil | ∅6.73 × W11.43 | 904 | 7.0–15.0 | 102 | 5.9 | IHI | NA |
| 13 | East-terrain line, Aichi, Japan | Subway | Clay, sand | ∅6.73 × W11.43 | 123 | 12.0–13.0 | 102 | 0 | IHI | NA |
| 14 | Nenjiang Rd. St. to Xiangyin Rd. St. to Huangxing greenbelt St., line 8 Shanghai Metro, China | Subway | Silty sand, silty clay, clayey silt | ∅6.52 × W11.12 | 1759 | 5.2–12.0 | 495 | 2.8 | IHI | 2003–2004 |
| 15 | Kairu Rd. St. to Nenjiang Rd. St., line 8, Shanghai Metro, China | Subway | | | 929 | 5.2–12.0 | 495 | 2.8 | MHI | 2003–2004 |
| 16 | Lot 9, line 6, Shanghai Metro, China | Subway | | | 1713 | 4.0–21.0 | 300 | 2.7 | IHI | 2004–2005 |
| 17 | Lot 10, line 6, Shanghai Metro, China | Subway | | | 2497 | 6.0–13.0 | 990 | 1.5 | IHI | 2004–2005 |
| 18 | Lot 11, line 6, Shanghai Metro, China | Subway | | | 1096 | 6.0–10.0 | 420 | 2.7 | IHI | 2004–2006 |
| 19 | Lot 10, line 3, Shanghai Metro, China | Subway | | | 1459 | 12.3–19.8 | NA | NA | IHI | ~2009 |
| 20 | Lot CA450A,Taoyuau International Airport Access MRT, Taiwan | MRT | Silty clay, silty sand | ∅6.42 × W11.62 | 1584 | 7.6–26.0 | 280 | 4.9 | IHI | 2009–2010 |

of view, limited information regarding the construction cost and duration for both single-circular and DOT shield tunneling methods was reported in the literature. In this article, the speed and duration of DOT shield tunneling for the construction of TIAA MRT were collected and compared with values suggested by Shield Tunneling Association of Japan (2004). A comparison of tunneling cost between single-circular twin-tube and DOT shield tunneling was also made.

## 2. DOT shield tunneling in Taipei basin

The objective of Taoyuan International Airport Access MRT is to provide airport passengers with a safe, convenient, comfortable and high quality transit service. TIAA MRT system between Taipei and Jhongli will link the Taoyuan International Airport to the Taiwan High Speed Rail (HSR), Taiwan railway systems, and Taipei MRT systems. The total budget for this project is approximately US$ 3.56 billion.

As illustrated in Fig. 1, the project starts from Taipei Main Station (A1 Station), passes through Sanchong, Sinjhuang, Linkou, Taoyuan International Airport (A12–A14a Stations), and terminates at Jhongli Train Station (A21 Station). The route intersects Taiwan High Speed Rail at HSR Taoyuan Station (A18 Station). The total route length is 51.03 km, consisting of 10.92 km of underground section and 40.11 km of elevated section. In Fig. 1, the TIAA MRT system has 22 stations, consisting of 7 underground and 15 elevated stations. The expected revenue service date for entire system is October 2014.