Cases study on application of rectangular shield jacking machine

Trisha Sun, W&M Consultants. Singapore, Zhang daoguang, Yangzhou Guanxin, China, Yu bingquan, Yangzhou Guanxin, China,

Abstract:

The paper will discuss and share the knowledge/experience in the application of rectangular shield jacking method via case study. It will highlight that the basic concept of design, construction and machine manufacture through projects which had been carried out in China and Singapore.

Meanwhile, the comparison between different methods of Rectangular shield jacking and Pipe roof will also be made via two example projects which had been executed in China and Singapore. The comparison will focus on not only the cost and quality of projects but also schedule and environment protection of the projects.

The Rectangular jacking projects explored in the case study are as followings:

- Four 4.9m X 6.9m (OD) parallel rectangular jacking project in Foshan, China. The project was completed in 2012. Refer to chapter B in the paper.

The pipe roof method jacking project is presented below:

- 4m X 6m (ID) Outlet Drain at North Buona Vista Road, Singapore. The project was completed in 2005. Refer to chapter C in the paper.

In conclusion, this paper deals with the consideration of the design and construction for rectangular shape underground crossings. It also highlights the key issues to be considered in the construction method selection at earlier stage of the project. The problems encountered during the construction, subsequent solutions adopted as well as monitoring of settlement will also be briefly discussed in the paper.
A. General

Pipe jacking is currently a common construction method for the underground structure of pipe line; normally by circular pipes are used in the practice.

Due to increasing requirements of rapid urbanization, more pipe lines such as the water supply, sewer, cables, traffic etc. have to make full use of underground space and this will cause more opportunities or challenges to develop the underground networking especially in the congested city areas.

In order to minimise the diversion of existing underground networking and the influence of the heavy traffic during the construction of underground pipe lines or structures, the use of rectangular shield jacking may be considered especially where limited head room is available.

This paper will discuss the rectangular shield jacking from the perspective of design, manufacture and construction via projects which had been practiced successfully in mainland of China. Part of the projects which had been constructed by method of rectangular shield jacking summarised in Table -1 as followings.

Table-1, Examples of the rectangular shield jacking projects ¹

<table>
<thead>
<tr>
<th>S/N</th>
<th>Project name</th>
<th>Jacking Length (m)</th>
<th>Period of construction (Month)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Underground Access at Kaiming Street and Medicine Street, Ningbo, Zhejiang</td>
<td>2 X 50</td>
<td>Jun 2006 - Sept 2006 ( 4 )</td>
</tr>
<tr>
<td>2</td>
<td>4th entrance of Longyang Road Station Shanghai Metro</td>
<td>1x 40.5</td>
<td>Nov 2006- Dec 2006 ( 1)</td>
</tr>
<tr>
<td>3</td>
<td>5th and 6th entrance at Qibao Station Shanghai Metro</td>
<td>2 x 56</td>
<td>Jan 2007- Mar 2007 ( 3)</td>
</tr>
<tr>
<td>4</td>
<td>Exit 4 at Spring Road Station, 9th Line, Shanghai, Metro</td>
<td>1 x 44.8</td>
<td>Apr 2007- May 2007 ( 2)</td>
</tr>
<tr>
<td>5</td>
<td>Underground access at Zhongshan hospital, Shanghai</td>
<td>1 x 78.5</td>
<td>Sept 2010- Feb 2011 ( 4)</td>
</tr>
<tr>
<td>6</td>
<td>2nd Entrance at 7th line, South Chen Road Station Shanghai Metro</td>
<td>1 x 37.3</td>
<td>Aug 2008- Oct 2008 ( 3)</td>
</tr>
</tbody>
</table>

¹ Source from Guangxin, Yangzhou manufacture
Projects summarised in Table - 1 are more for entrance and exit to underground train stations, underground pedestrian crossings, underground connections/access between existing buildings, outlet drain etc. The rectangular shield method had been in use in China since 2005. It had been further developed and improved via increasing market demand during the last 10 years.

1. Design consideration:

The rectangular shield jacking is considered as a more efficient and safer construction method for underground structures especially in the congested areas of the cities. However, feasibility study has to be carried out in the preliminary design stage in order to evaluate the project from the perspective of quality, cost, schedule, and environment protection.

The following factors are essential for the adoption of rectangular shield jacking method.

- Soil condition
• Surrounding existing building and structure conditions
• Surrounding utilities and traffic conditions
• Shaft location, sizes, jacking force and soil treatment if necessary
• Pipe design and materials
• Pipes connection and water proofing.
• Environment protection

2. Manufacture of the machine

The jacking equipment is one of the important factors for the successful completion of rectangular shield jacking project; this chapter will focus on the discussion of the cutter head design and the special Sand/Soil pump which has to be put in place to control alignment deviation during operation.

2.1. Cutter head

There are three types of the cutter head design used in the projects listed in Table-1. Type 1 is the mix and overlapped type as shown in Fig-1. This cutter head consist of one bigger cutter (extend forward) in the centre and four smaller cutters (receding) in each corner of the rectangular surface. It forms a combination of overlapping surface.

![Fig 1. Type-1, Mix cutter design](image)

Type 1 cutter head had been used in most of the Projects as listed in Table-1, e.g. Projects in Shanghai, Nanjing, Guangzhou and Huizhou, the soil condition is more for clay, sandy soil, silt, fine sand etc. One project needs to be highlighted; it is an underground connection access to two existing old buildings at Zhongshan hospital Shanghai, China. The rectangular shield jacking is operated below existing oxygen

---

2 Picture from Yangzhou Guangxing, China
station and substation which required minimal soil movement and settlement. The same cutter head been used for this project.

The advantage of this type is the ease of operation, flexibility for direction control and stability of jacking. There is minimum settlement after construction. However, it will not perform well in the soil condition of high cohesive soil and bigger N value due to the 8% of blind areas existed in the cutter areas. Meanwhile, the deformation of the shell of the machine been found when the machine goes through strengthened soil treatment areas in the shafts (when the strengthening soil strength is more than 10 Mpa).

Type 2 of the cutter is the multi cutter arrangement as shown in Fig 2. It had been used in Project number 14 in Table-1. This type is broken up in two parts (Top and Bottom) for easy installation and transportation. Meanwhile, the blind zone is much smaller as compare with Type1.

![Fig 2 Type 2, Multi cutter arrangement](image)

Type 3 is Epicyclic Gearing transmission system with the full section cutting without blind point arrangement. It had been used in projects in harder ground conditions, such as consolidation sandy soil and soft rock.

![Fig. 3. Epicyclic Gearing transmission with full section cutter type](image)

---

3 Source from Yangzhou Guangxin, China
4 Source from Yangzhou Guangxin, China
2.2. Soil/Sand pump to rectify the deviation

Rectangular shield pipe jacking construction in general is very difficult to control the alignment deviation due to the size and mess of the machine. In order to control and correct the deviation, the special Sand/Soil pump is essential for the successful implementation of the projects.

Projects listed in Table-1 had been successfully implemented with the use of Sand/Soil pump during construction. Fig.4 shows the picture of the Sand/Soil pump and the disposal from execution of the projects.

![Fig 4, Soil and Sand Pump](image)

(Patent certification Number is 200720067906, 200820059282, 201220472450)

The grouting holes had been provided in the rectangular shield machine as Fig.5. It will be used during rectifying the deviation, if necessary, during the operation.

![Fig 5, Grouting holes in the rectangular shield machine](image)
3. Construction consideration

3.1. Construction proceeds:

It is important to emphasize the rectangular pipe jacking construction process as outlined below, Fig.6

1. Control theory soil pressure

2. Control Jacking pressure or adjustment

3. Decision of operation condition or adjustment

4. Preliminary Test Run

5. Equal Balance between internal chamber pressure and control pressure

6. Equal Balance between disposal volume and jacking space (95% to 100%)

7. Ground settlement ±5mm

8. Jacking in common process

Fig.6 Construction program

7 From 2nd rail construction china for Foshan project
3.2 Principle for construction of Rectangular pipe jacking

The construction of the pipe jacking is the process of the pipe line being jacked from the working shaft to the receiving shaft by the jacking machine. Fig 7 shows the pipe jacking system starting from working shaft.

[Diagram showing the process of pipe jacking]

3.3. Key issue to be considered in Rectangular Jacking

- Deviation in the process of jacking
- Technology of the soil treatment during jacking process
- Balance between friction and grouting during jacking process
- Control of soil movement during the jacking
- Control and operation skill in the in and out from working and receiving shaft
- The settlement control after jacking

3.4. Comprehensive issues in the jacking process

- Water stop in the working shaft during jacking
- Soil treatment during breakthrough in the receiving shaft.

---

[8] Source from 2nd rail construction of China
B. Rectangular Pipe Jacking Project

1. Project briefing and discussion

The project is consist of four parallel underground commercial retail and vehicle passes, each of dimension 4.9m x 6.9m in Foshan, China. It is also an underground connections between two exiting buildings located at Nanhai street, Foshan, Guangdong, China.

The project is located at the an area with complex and heavy traffic flow, as well as a proposed MRT rail of 2 circle lines below the project itself. Meanwhile, the exiting concrete drain (4.2m X 2.5m) is directly above the project with 500mm distance from bottom of the drain to top of the tunnels. The depth of the project is 5.5 meter from the road surface to top of the pipe lines, the soil condition is clay, fine sand silt and sandy soil.

For more details and discussion refer to following. (Fig. 8 to Fig.16)\(^9\)

---

Fig.8 Completed underground connections tunnels

Fig 9. Layout for 4 parallel underground connection tunnels

\(^9\) Foshang project, 2nd Rail Construction, China
Fig 10. Longitudinal section of connections between two buildings
(Jacking distance is around 55 meter for each line)

Fig 11. Section through 4 parallel tunnels
(300mm space in between pipe lines, 2 meter length of rectangular concrete pipes and 450mm thick of the pipe)

Fig 12. Section of soil profile and the constraint of construction space
Prestressed strand had been provided for the concrete pipes to enhance the longitudinal stiffness.

**Fig.13** Jacking from break out (working shaft) to break through (receiving shaft)

Site Photos during construction
(constructin sequence is line1, line3, line 2 and line4)

<table>
<thead>
<tr>
<th>Utilities</th>
<th>Diameter/dimension</th>
<th>Depth in the ground (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Water supply steel pipe</td>
<td>300 mm dia</td>
<td>1.04</td>
</tr>
<tr>
<td>Tel com</td>
<td>18 Nos of 600<em>300 (mm</em>mm)</td>
<td>1.01</td>
</tr>
<tr>
<td>Water supply concrete pipe</td>
<td>800mm dia</td>
<td>1.24</td>
</tr>
<tr>
<td>Gas pipes</td>
<td>219 mm dia</td>
<td>0.81</td>
</tr>
<tr>
<td>Drainage concrete</td>
<td>4200<em>2500(mm</em>mm)</td>
<td>4.37</td>
</tr>
<tr>
<td>Sewerage pipes</td>
<td>500mm dia</td>
<td>4.32</td>
</tr>
<tr>
<td>Power supply</td>
<td>1200<em>1200(mm</em>mm)</td>
<td>0.52</td>
</tr>
</tbody>
</table>

**Fig.15** utilities layout and details
Fig. 16 Settlement diagram
(Maximum settlement is 22mm according to the monitoring report)

2. Construction schedule

From the construction record as Table 2 and 3, it expressed that the jacking speed had been well satisfied if comparing with the common practice of using circular pipes.

Table-2 Jacking schedule\textsuperscript{10}

<table>
<thead>
<tr>
<th>Items</th>
<th>Line1</th>
<th>Line 2</th>
<th>Line 3</th>
<th>Line 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Length (meter)</td>
<td>60.5</td>
<td>60.5</td>
<td>60.5</td>
<td>60.5</td>
</tr>
<tr>
<td>Date of start</td>
<td>9-Dec-11</td>
<td>22-Mar-12</td>
<td>13-Feb-12</td>
<td>28-Apr-12</td>
</tr>
<tr>
<td>Date of completion</td>
<td>13-Jan-12</td>
<td>12-Apr-12</td>
<td>6-Mar-12</td>
<td>15-May-12</td>
</tr>
<tr>
<td>Average speed of jacking</td>
<td>1.78</td>
<td>2.75</td>
<td>2.75</td>
<td>No record</td>
</tr>
<tr>
<td>(meter / day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maximum speed of jacking</td>
<td>4.5</td>
<td>6</td>
<td>7</td>
<td>7.5</td>
</tr>
<tr>
<td>(meter / day)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Table -3 Shaft construction schedule\textsuperscript{11}

<table>
<thead>
<tr>
<th>Shafts</th>
<th>Date of start</th>
<th>Date of completion</th>
</tr>
</thead>
<tbody>
<tr>
<td>Receiving shaft</td>
<td>Oct, 2011</td>
<td>Dec, 2011</td>
</tr>
</tbody>
</table>

\textsuperscript{10} from 2nd rail construction, China
\textsuperscript{11} from 2nd rail construction, China
C. Practice Pipe Roof Project\textsuperscript{12}

1. Project briefing

The project is Tanglin Halt Outlet Drain at North Buona Vista Road comprising the design and construction of a 120m long permanent RC (reinforcement concrete) box culvert, sewer diversion and other related works located along Commonwealth Avenue, Commonwealth Avenue West and North Buona Vista Road, Singapore.

Part of the works under this contract is the construction of approximately 53m of drainage box culvert (4m X 6m) under-crossing North Buona Vista Road using approved tunneling method. The jacking is from Jacking shaft to receiving shaft as shown in Fig.17

![Fig. 17 Project Layout](image)

Refering to Fig.17, the yellow portion is the proposed rectangular drainage box culvert, the red line is existing east west (EW) overhead MRT viaduct, and the purple line is the circle MRT line underneath of tunnel. For more information, read the Fig17 in conjunction of Fig.18

![Fig.18 Longitudinal section of drainage box culvert](image)

\textsuperscript{12} Paper related to the project published in International conference and exhibition on tunnelling and trenchless technology, Year 2011 by the Institution of Engineers, Malaysia.
Fig. 19 General soil profile of the mined tunnel zone

Fig. 20 Utilities and protection measures adopted

2. Discussion

The temporary earth retaining structure to support the ground during the excavation of the mined tunnel consists of a series of 780mm diameter, 16mm thick circular steel pipes interconnected by clutch to form an inverted U pipe-roof structure around the footprint of the proposed drain.

The pipe roof method was adopted for the project due to site constraint. It was formed by 22 rows of steel pipes, comprised of 10 at top and 6 on either side. The interlocking steel pipes forming the pipe roof together with the support system shown in Fig.22 and 23. Moreover, the 22 numbers of steel pipes will be left in the underground space as it has no more function after the completion of the outlet drain construction.
Fig. 21 Details of pipe clutch

Fig. 22 Transverse view of interlocking pipe roof

Fig. 23 Complete pipe roof with interlocking pipes

Fig. 24 Layout of instrumentation and monitoring system settlement monitoring
From Fig. 25 and 26, it can be seen that the actual settlement of 30mm is well controlled within the predicted value of 50mm.

D. Comparison between pipe roof and rectangular shield jacking

From chapter B and chapter C in the paper, Case Studies carried out for two projects in almost similar basic conditions are summarised as followings:

- Similar size of 4m X 6m(ID) for the rectangular underground structure,
- Constraint by heavy traffic above the rectangular underground structure,
- Existing /proposed MRT tunnel below the rectangular underground structure for project in chapter C and B respectively,
- Existing joint bay above the proposed tunnel for project in chapter C,
- Existing concrete drain above the tunnel for project at chapter B,
- There are many utilities surrounding the rectangular underground structure without diversion before construction,

Both projects were completed in year 2005 and 2012 respectively by different construction methodology - pipe roof and rectangular shield pipe jacking. It were considered as successful during the time of the completion. However, it become significant for further study and discussion according to the technology of rectangular shield pipe jacking which are used recently in the world.

The detailed comparisons between two methods of construction had been summarised in Table 4 of the paper. It highlighted several areas of interest in the construction methodology for us to further study and consider before the commencement of future projects.
Table - 4. Comparison Between Pipe Roof and Rectangular shield Pipe Jacking

<table>
<thead>
<tr>
<th>Nos</th>
<th>Items to compare</th>
<th>Rectangular shield jacking project (Chapter B)</th>
<th>Pipe roof project (Chapter C)</th>
<th>Remarks</th>
</tr>
</thead>
</table>
| 1   | Site constraint and condition | • Heavy traffic above  
• Existing MRT (two circle line) below  
• MRT Viaduct near by the project | • Heavy traffic above  
• Proposed MRT and Mechanical room below (three circles) | Quite similar conditions                     |
| 2   | Utility condition         | Joint bay above the Refer to Fig.18 and Fig 20                                                               | Existing drain above Refer to Fig.12                                                              |                                               |
| 3   | Soil condition            | Sand and sandy soil                                                                                           | Clay, Sand and sandy soil                                                                         |                                               |
| 4   | Size of jacking section (ID, m*m) | 4 X 6                                                                                                          | 4 X 6                                                                                              |                                               |
| 5   | Jacking length (meter)    | 242 (60.5 X 4 )                                                                                               | 50                                                                                                 |                                               |
| 6   | Construction Period (Month) | 11                                                                                                             | 22                                                                                                 | Including shafts                              |
| 7   | Maximum Settlement (mm)   | 22                                                                                                             | 30                                                                                                 | Refer to Fig.16, 25,26                        |
| 8   | Contract sum (Million)    |                                                                                                                |                                                                                                    |                                               |
| 9   | Environment               |                                                                                                                | Pipe roof occupied underground space                                                              | Refer to Fig.22, 23                           |
Acknowledgment

The authors would like to thank for all who contribute for the paper. Yanzhuo Guangxin, China, 2nd Rail construction, China and Or Kim Peow Contractors (Pte) Ltd (OKP), Singapore for this paper.

The views presented in the paper are solely that of the authors, unless otherwise stated.

References:

- LTA 2009a, LTA interpretive soil report for C 8288.
- LTA 2009b, Correspondence between OKP/LTA and Authorities (LTA comments on contractor’s response to LTA earlier comments on DAR 8288/CON/0019(DATED 7 May 09)).
- LTA 2009c, LTA Civil Design Criteria
- LTA 2009e, Code of practice for works on Public Street.
- Parsons Brinckerhoff, 2009, Design Report for Mined Tunnel submitted to LTA.
- Wong K S, O/ 2009, Independent report on Tanglin Halt Outlet Drain-mined tunnel.
- Report from Seminar on 2012 for Foshang project, 2nd Rail Construction, China