BOX TUNNEL JACKING METHOD AT PEDESTRIAN CROSSING TUNNEL KOTA

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ABSTRACT

Two connected pedestrian crossing tunnels located in the crowded old city of Jakarta are being constructed. These tunnels will cross the crowded Jalan Stasiun Kota and Jalan Pintu besar Utara and connect Beos Railway Station at the East side, Busway Station and Museum Mandiri at the West Side.

The 1000-ton precast concrete box tunnels are to be advanced by a jacking construction technique. At present, the west side box tunnel has been successfully jacked in, while the east side box tunnel is to be jacked in the near future. The condition of the soft soil made this method seem impracticable in the beginning. However, with some modification from the early design method, a method for calculating the required the jacking force was developed.

The recorded jacking force from the west side box tunnel is presented and evaluated to obtain useful information for better designs and construction of similar in the future. Conclusions and recommendation are finally given.

Key words: friction force, restrained force, end bearing

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INTRODUCTION

One of the main problems of Jakarta is the traffic congestion happening almost everywhere in the city area. In Stasiun Kota area, especially due to the development of Busway Station in front of the railway station generating people crossing the busy streets of Jalan Stasiun Kota and Jalan Pintu Besar Utara, the congesting progressively worsens.

Nowadays, in every hour there are 2,600 pedestrians crossing both streets, from the Beos Railway Station to the front of Bank Mandiri Museum and vice versa. On both
streets, it is estimated that there are 2,400 vehicles passing on that area in every hour. The combination of the two raises the issue of safety for both the pedestrians and the vehicle drivers.

Ideally, stations for these mass transportation systems (railway and busway systems) have to be integrated to minimize the mentioned problems. To realize this matter, a connector between Beos Railway Station and Busway Station is needed. There were 2 alternatives: Pedestrian Crossing Bridge (JPO) and Pedestrian Crossing Tunnels (TPO). At the end, the second alternative was chosen mainly to conserve the historical and architectural aspect of “Kota Tua” district.

There are also additional issues to be addressed. Because of the high traffic volume in this Kota area, the main requirement in the development of the TPO is that the entire road surrounding the project cannot be closed or transferred and also the traffic congestion effect due to this development process has to be minimized. In addition, there are many utilities, such as cables and pipes, in this tunnel area which irremovable during the construction period. After considering these issues, the Box Tunnel Jacking Method is selected as the best alternative for this TPO Kota development.

TPO Kota consists of 2 parts, Station Kota tunnel side (east side, 24 m long) and Museum Bank Mandiri tunnel side (west side, 21 m long). In between these tunnels,
there is Taman Stasiun Kota (figure 1). Each box tunnel has dimension of height and width 4.95 m x 10.10 m and total weight 1900 ton.

It is noted that the Box Tunnel Jacking Method has been employed two times in Indonesia, first at Dukuh Atas Tunnel and second at Manggarai Tunnel, however the limited area and the poor soil condition at the stasiun Kota area cause the needed of modification in the method of construction compared to the past similar projects.

**SUBSURFACE CONDITION**

The subsurface information was obtained through two (2) geotechnical investigations. The investigations involved the pushing of four (4) mechanical cone penetration tests (CPTs) and the drilling of six (6) boreholes to a maximum depth of 30 m. The CPTs were carried out to a layer with cone resistance of 20 MPa, at depths between 17 and 20 m. At each borehole, standard penetration tests (SPTs) were carried out at 1 to 2 m intervals, and undisturbed samples were also taken at depths. Conventional laboratory tests, including classification tests, unconfined compression tests, triaxial compression tests, oedometer consolidation tests, were carried out.

Figures 2a and 2b show the CPT and borehole information along the tunnel alignment for the west and east side box tunnels, respectively. The groundwater level was relatively close to the surface, typically 1 to 3 m below the ground surface.
The box tunnels (depths between 8 to 9 m) was mainly within layers of very soft, grey clay-silt-fine sand geomaterials with CPTs cone resistance of 0.2 to 0.5 MPa and N-SPT values of 1 to 3 blows per 0.3 m penetration.

The bearing layer for the driven piles was very hard, brown silt-clay at depths of between 15 to 18 m. The CPTs cone resistance was greater than 15 MPa and the N-SPT values were greater than 50 blows per 0.3 m penetration.

Figure 2a. Subsurface Information for West Side Tunnel

Figure 2b. Subsurface Information for East Side Tunnel
SETTLEMENT ANTICIPATION

Tunnel Construction with Box Jacking Method is not a new matter in Indonesia, at least has been employed twice. However, the main problem and the challenging matter is how to minimize the box tunnel settlement when the jacking is conducted. One of the tunnels is the Dukuh Atas Tunnel. The settlement and the associated inclination of the 51.25 m long tunnel were 0.468 m and 0.9%, respectively.

In the design, Design Consultant proposes the same construction method which has been conducted to The Dukuh Atas Tunnel. However, with the soil condition which is very soft, SPT value only 1 -2 at depth of 7 – 8 m, so the potential settlement could be larger, compared to that of Dukuh Atas tunnel for the same construction method. Therefore, construction method that is proposed by the Design Consultant has to be changed or modified in order to minimize the settlement that will occur.

To minimize the settlement, some measures have to be taken:

1. Reducing working load on the jacked box tunnel.
2. Keeping the soil condition in the box tunnel alignment in undisturbed condition, so that the relative soil resistance does not change significantly.

The early design of Design Consultant, following the Dukuh Atas Tunnel, calls for two tunnels directed from Taman Stasiun Kota to Mandiri and Beos, consisting of 3
segments each, pushed one by one in turn until reach final position, as shown in figure 3a – 3d.

Figure 3a. Jacking Installation according to Design Consultant proposal.

Figure 3b. Jacking of Segment 1 according to Design Consultant proposal.
Figure 3c. Jacking of Segment 2 according to Design Consultant proposal.

Figure 3d. Jacking Segment 3 according to Design Consultant proposal.
The Design Consultant also calls replacement of surface pavement with metro deck system with main steel beams parallel to the box tunnel alignment, as shown in fig. 6.

Figure 4. Early design Metro Deck structure according to Design Consultant.

Figure 5. Modified design of metro deck structure to reduce load on the box tunnel
To minimize the direct effect of vehicle loads on the box tunnel, a new design of metro deck system was proposed in which the main steel beams is to be placed perpendicular to the box tunnel alignment. In other words, the metro deck system would function as a bridge, as shown in fig. 5 and 6.

![Metro deck installation with the main beam placed parallel to centre line of the street](image)

Figure 6. Metro deck installation with the main beam placed parallel to centre line of the street

Based on the past experience in which segments of box tunnel were pushed in sequence resulting in settlement with inclination angle of about 0.9%, a number of measures were proposed to address this issue. First, the casting yard for box tunnel concreting has to be constructed as flat as possible, so that no differential settlement would exist to cause early inclination. Second, the casting yard must not deform due
to jacking load. Therefore, the casting yard foundation was made of deep foundation and was also of batter piles to provide greater horizontal resistance to jacking (fig.7).

Figure 7. Pile and batter pile for casting yard foundation

Figure 8. Plan of box tunnel concreting area and metro deck location
Third, the box tunnel jacking had to be performed as a single tunnel, not 3 segments of tunnel. Therefore, the 3 segments were joined by pre-stressed cables, as shown in figure 9 and 10.

Figure 9. Box tunnel lay out and Hydraulic jack position

Figure 10. Box tunnel first jacking with steel bracket for transferring reaction force to the casting yard
By applying the principles that have been explain above, at the end of Mandiri Side Jacking, it was recorded that the settlement of the box tunnel is zero with horizontal alignment about 2 cm, caused by the ancient foundation structure (Fig. 11) that was found in the last 4 meter from the final position.

Figure 12. The old foundation structure that block out the box tunnel
**JACKING FORCE**

The recorded jacking force graphic from Mandiri Area is shown in figure 12. As we see here, this graphic has 3 trend-line. The first trend shows the jacking forces as the whole box tunnel still on the casting yard, while the second and the third, figuring the forces when the box tunnel entering the soil until reach its the final position.

![Figure 12. Recorded Jacking Force](image)

The Mean value of the first trend-line gives us the friction coefficient between the box tunnel and the casting yard or between steel and concrete, because steel plate was used for the bottom part of the box tunnel form work. From this dataset we get that the average friction coefficient of steel-concrete is 0.301, with its minimum value 0.245 and maximum value 0.364.
The second trendline has a positive gradient while the third has a negative. From the field it was known that when the box tunnel has moved around 17 meter (at the end of trendline 2), an old foundation structure was found. This structure, made from very hard natural stone, blocked the jacking activity (fig.11), and they had to move out manually before we started again. Therefore when we start to jack again, that is the beginning of trendline 3, the jacking forces are relatively less than before and have a negative gradient, because actually we have dug in front of the box tunnel.

Figure 13. Part of corrected Jacking Force – Trendline 2 used for soil’s parameter calculation

Considering the complexity in trendline-3, it’s reasonable to used part of trendline-2 for calculating soil’s parameters. Figure 13 shows part of jacking forces-trendline-2 that have been corrected by eliminating the friction force between box tunnel and casting yard. With assumption $C_a = 30 - 40 \text{ kN/m}^2$ and $K_0 = 0.7 - 0.9$, we can
simulate the dataset to get the range value of $\mu$ (friction coefficient between concrete and soil) and $S_b$ (End bearing stress of the box tunnel), as shown in table 1.

Table 1. Variation of $\mu$ and $S_b$

<table>
<thead>
<tr>
<th>$C_a$</th>
<th>$K_o$</th>
<th>$\mu$</th>
<th>$S_b$ (kN/m$^2$)</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>0.7</td>
<td>0.33</td>
<td>138.80</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>0.32</td>
<td>135.74</td>
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<tr>
<td></td>
<td>0.9</td>
<td>0.31</td>
<td>132.88</td>
</tr>
<tr>
<td>35</td>
<td>0.7</td>
<td>0.27</td>
<td>123.43</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>0.26</td>
<td>120.97</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0.25</td>
<td>118.67</td>
</tr>
<tr>
<td>40</td>
<td>0.7</td>
<td>0.20</td>
<td>107.36</td>
</tr>
<tr>
<td></td>
<td>0.8</td>
<td>0.20</td>
<td>105.51</td>
</tr>
<tr>
<td></td>
<td>0.9</td>
<td>0.19</td>
<td>103.77</td>
</tr>
</tbody>
</table>

Using these values from table 1, a range of jacking forces for the Beos Tunnel Side can be calculated and shown in table 2 with $H$ is the height of the soil in front of the box tunnel, measured from the bottom elevation of box tunnel.

Table 2. Range of Jacking Force for Beos Side

<table>
<thead>
<tr>
<th>C</th>
<th>$S_a$</th>
<th>$K_o$</th>
<th>$\mu$</th>
<th>$S_b$ (kN/m$^2$)</th>
</tr>
</thead>
</table>