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ANALISIS PERENCANAAN SEGMEN CULVERT BOX DAN BORED PILE PADA TEROWONGAN DENGAN METODE *JACKING BOX TUNNEL*

ANALYSIS OF BOX AND BORED PILE SEGMENT PLANNING IN TUNNEL USING JACKING BOX TUNNEL METHOD
(CASE STUDY: PEDESTRIAN OF JURANG MANGU STATION – BXC MALL, BANTEN)

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Abstrak— Jacking box tunnel adalah sebuah metode konstruksi pembuatan terowongan yang menjadi solusi ketika terdapat bangunan lain yang berdekatan dengan area pembuatan terowongan. Jacking box tunnel juga menjadi solusi ketika tidak dimungkinkan penggunaan metode galian terbuka. Penggunaan Segmen Culvert Box yang dimasukkan kedalam tanah, dapat meminimalisir dampak terhadap bangunan disekitar sehingga stabilitas tanah dapat tetap dijaga. PT Jaya Real Property menyediakan akses terowongan pedestrian untuk menghubungkan Stasiun Jurang Mangu dengan BXC Mall. Terowongan ini memiliki panjang total rencana 161,4 meter, yang terdiri dari total 4 Segmen Culvert Box. Pada area Segmen Culvert Box 3 beririsan dengan abutment jalan tol eksisting Jakarta-Serpong, oleh karena itu agar tidak mengganggu abutment eksisting digunakan metode konstruksi Jacking Box Tunnel. Pada studi ini dilakukan analisis perencanaan pada terowongan yang menggunakan metode konstruksi tersebut. Hasil menunjukkan dengan perencanaan Segmen Culvert Box 3 sepanjang 41,7 meter, pelaksanaan Jacking Box Tunnel membutuhkan area kerja sedalam 7,6 m dari permukaan tanah asli. Pada studi ini, terdapat 3 kelompok bored pile yang digunakan untuk menahan tanah dalam pembuatan area kerja dan mendukung pelaksanaan proses jacking berdasarkan kondisi beban yang ada. Bored pile 1 dan Bored pile 3 direncanakan menggunakan diameter 600 mm dengan tulangan 18 – D25, sedangkan Bored pile 2 menggunakan diameter 800 mm serta tulangan 18 – D25. Selanjutnya, struktur Segmen Culvert Box terbuat dari beton bertulang dengan diameter tulangan 22 mm dan kebutuhan beban jacking sebesar 4901,9512 kN untuk mendorong Segmen Culvert Box. Satu Segmen Culvert Box membutuhkan 2 buah hydraulic jack dengan kapasitas maksimum satu hydraulic jack sebesar 400 ton.

Kata kunci— Segmen Culvert Box, Bored Pile, Jacking Box Tunnel, Terowongan, Analisis perencanaan

Abstract— *Jacking box tunnel is a tunnel construction method which can be a solution when there are other buildings adjacent to the tunnel construction area. Jacking box tunnel is also a solution when the use of open excavation methods is not possible. The use of Culvert Box Segments inserted into the ground can minimize the impact on surrounding buildings so that soil stability can be maintained. PT Jaya Real Property provides pedestrian tunnel access to connect Jurang Mangu Station with BXC Mall. This tunnel has a total planned length of 161.4 meters, consisting of a total of 4 Culvert Box Segments. In the Culvert Box Segment 3 area, it intersects with the existing Jakarta-Serpong toll road abutment, therefore in order not to interfere with the existing abutment, the Jacking Box Tunnel construction method is used. In this study, a design analysis was carried out on a tunnel using this construction method. The results show that with the planning of Culvert Box Segment 3 along 41.7 meters, the implementation of the Jacking Box Tunnel requires a work area as deep as 7.6 m from the original ground surface. In this study, there are 3 groups of bored piles used to hold the soil for working area and supporting the implementation of the jacking process based on the existing load conditions. Bored pile 1 and Bored pile 3 are planned to use a diameter of 600 mm with 18 - D25 reinforcement, while Bored pile 2 uses a diameter of 800 mm and 18 - D25 reinforcement. Furthermore, the structure of the Culvert Box Segment is made of reinforced concrete with a reinforcement diameter of 22 mm and a jacking load requirement of 4901.9512 kN to push the Culvert Box Segment. One Culvert Box Segment requires 2 hydraulic jacks with a maximum capacity of one hydraulic jack of 400 tons.*

Keywords— *Segmen Culvert Box, Bored Pile, Jacking Box Tunnel, Tunnel, Design analysis*

I. Introduction

The Cut and Cover method is one of the most commonly used techniques in tunnel construction. This method involves excavating a trench in the ground, followed by the construction of the tunnel's walls and roof, and subsequently backfilling the trench so that the entire structure is embedded underground. However, this method presents several limitations, especially in urban environments. Significant horizontal displacement risks to nearby structures and the disruption of traffic flow often lead project planners to consider alternative designs. One such alternative is the Jacking Box Tunnel method.

The Jacking Box Tunnel method works by inserting precast concrete box culvert segments into the ground using hydraulic jacks. This technique is considered to be safer, particularly for tunnel construction projects located near existing buildings or infrastructure.

PT Jaya Real Property initiated the construction of Bintaro Jaya Xchange Mall 2 to accommodate the growing needs of the Bintaro community in South Tangerang. As an area with high mobility, an accessible and safe pedestrian route was deemed essential to facilitate movement within the region. Consequently, PT Jaya Real Property provided a secure pedestrian access route connecting Bintaro Jaya Xchange Mall to Jurang Mangu Station.

The Jurang Mangu Station–BXC Mall pedestrian tunnel is located in Ciputat Subdistrict, South Tangerang, Banten. The planned pedestrian tunnel spans a total length of 161.38 meters and is divided into four segments, initially designed to be constructed using the open-cut method. However, Segment Culvert Box 3 intersects with the Jakarta–Serpong toll road, which is owned and managed by the Ministry of Public Works and Public Housing (PUPR) as part of the National Toll Road System (PUPR-JBH), located directly beneath the bridge abutment of the toll road.

Due to this intersection, an appropriate construction method is required to ensure that the tunnel can be built without compromising the surrounding structures. The open-cut method is not recommended in this context, as it could destabilize the soil and the existing toll road structure. Therefore, the Jacking Box Tunnel method is proposed to maintain soil stability near the toll bridge abutment during tunnel construction. A study conducted by Komiya on tunnel construction in Nagano Prefecture demonstrated that the horizontal displacement of railway tracks intersecting with the tunnel was less than 3 mm [1]. This method also allows traffic above the tunnel to continue operating without causing congestion [2]. Based on this evidence, a structural and implementation analysis of the pedestrian tunnel using the Jacking Box Tunnel method is conducted, focusing particularly on Segment Culvert Box 3, in order to minimize construction risks near the bridge abutment. Hung et al. (2009) further noted that the Jacking Box Tunnel method does not interfere with toll road traffic above the tunnel [3], and it is also versatile enough to be applied in various soil conditions [4].

This study discusses the structural design analysis of the Culvert Box segments using the jacking method, focusing on Segment Culvert Box 3 and determining the jacking force required to push the box segments into place. The Culvert Box segment in this project has a total length of 41.7 meters, divided into four sections, each 10.35 meters long, based on the pedestrian design specifications. This study also includes the design analysis of the retaining structure using bored piles, which will support the working area and facilitate the jacking process. The working area is designed at a depth of 7.6 meters below the original ground level on the side of Jurang Mangu Station, as the project site is located directly beneath the existing toll bridge abutment.

II. Research Methodology

This study involves two main structural design analyses: the analysis of the Culvert Box Segment structure and the Bored Pile structure. The Culvert Box Segment analysis pertains to the Jacking Box Tunnel design, while the Bored Pile analysis addresses the need to retain soil in the working area and to support the jacking operation. Figure 1 illustrates the planning stages involved in the structural analysis of both the Culvert Box Segment and Bored Pile.

In this study, the loads acting on the Culvert Box Segment include self-weight, additional dead loads, lane loads, earth pressure, and pedestrian loads. These loads are combined according to SNI 1725:2016. Among the various load combinations generated, the combination that produces the maximum moment is selected for further analysis [5].

Once the maximum moment is determined, the reinforcement design of the Culvert Box Segment is conducted using numerical calculations based on SNI

2847:2016. This includes structural calculations for the top slab, bottom slab, and side walls of the Culvert Box Segment [6]. The required jacking force to push the Culvert Box Segment into the ground is then calculated based on the segment's structural weight [7]. Subsequently, the number of hydraulic jacks required to drive a single Culvert Box Segment into the ground is also determined.

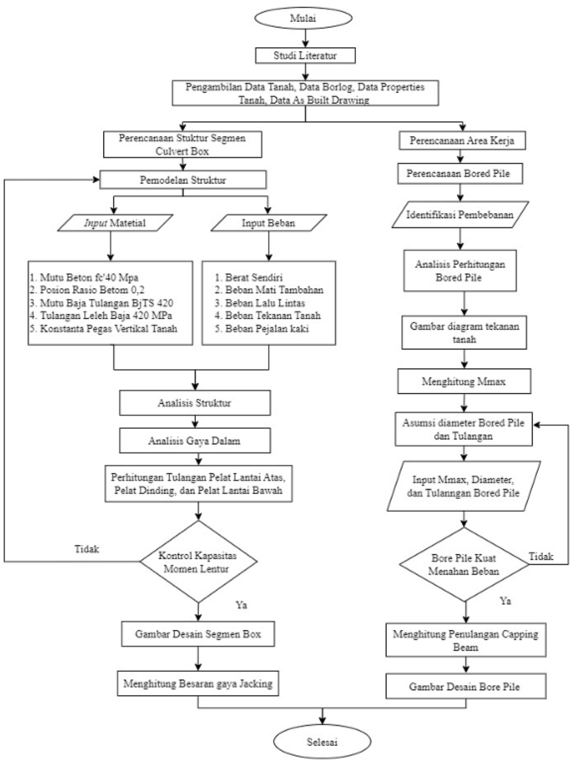


Figure-1. Flowchart of Culvert Box Segment and Bored Pile Design Process

Next, the Bored Pile is designed as a single pile structure subjected to lateral earth pressure and vehicular loads transmitted through the soil layers [8]. In this study, the Bored Piles are classified into three types (BP1, BP2, and BP3) based on the specific conditions and load scenarios at each location. Figure 2 shows the layout of the Bored Pile locations.

The calculation of lateral earth pressure in the Bored Pile design is used to determine the maximum bending moment and the required embedment depth to resist the applied loads [9]. The resulting maximum moment is then used to determine the appropriate pile diameter, longitudinal reinforcement, and shear reinforcement for each Bored Pile type [10].

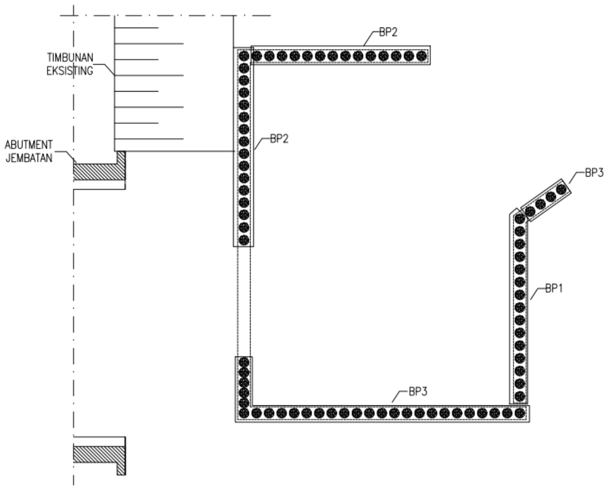


Figure-2. Bored Pile Location Layout

In this study, the SpColumn software is utilized to determine the required pile diameter, longitudinal reinforcement, and shear reinforcement. The results from the Bored Pile design are followed by an analysis of the capping beam requirements, which are needed to control deflection at the pile head.

The soil parameters used in this study are presented in Table 1, which lists the geotechnical data utilized in the design process [11].

Table-1. Soil Parameter Specifications

Layer	Soil Type	γ_{sat} (kN/m-3)	γ_{unsat} (KN/m-3)	c' (kPa)	Φ' (deg)
Fill	Fill	19	18	3,5	30
1	Clayey silt – Very soft	17	16	10	17
2	Clayey Silt – Soft to Hard	17	16	14	17
3	Silty Sand – Hard	19	18	150	30

III. RESULT AND DISCUSSION

A. *Structural Design of the Culvert Box Segment*

The cross-sectional view of the Culvert Box Segment is shown in Figure 3.

The design dimensions of the Culvert Box Segment used in this study follow those specified in the construction project plan [11], as detailed below:

Width of Culvert Box Segment	(L): 7,1 m
Height of Culvert Box Segment	(H): 4,65 m
Length of Each Box Segment	(Lb): 10,35 m
Total Length	(Lt): 41,7 m
Top Slab Thickness	(h1): 0,55 m
Wall Thickness	(h2): 0,55 m

Bottom Slab Thickness (h3): 0,6 m

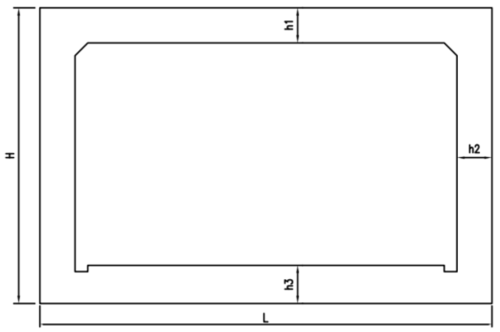


Figure-3. Cross-Section of Culvert Box Segment

Based on the obtained design data, the Culvert Box Segment was modeled with the loads acting along its structure. This modeling aims to determine the internal forces generated along the Culvert Box Segment. The resulting internal forces are then used to calculate the required reinforcement in the structural design of the Culvert Box Segment. For the foundation design of the Culvert Box Segment, concrete with a compressive strength of 40 MPa and reinforcement steel with a yield strength of 420 MPa are used.

B. Loading on the Culvert Box Segment

In this study, the applied loads on the box segment include self-weight, additional dead loads, lane loads, lateral earth pressure, and pedestrian loads.

The considered loads reflect those encountered during the construction phase. Load combinations are applied in accordance with SNI 1725:2016 [5], as outlined below:

1) Combination I

This load combination, which excludes wind loads under certain conditions, is based on structural actions affecting the bridge. Each nominal force is magnified by its corresponding load factor under this limit state.

2) Serviceability Condition 1 (Layan 1)

This combination includes all standard loads associated with bridge operation and considers wind speeds ranging from 90 km/h to 126 km/h. It is used to assess deformations in various structural components such as steel culverts, slabs, tunnel linings, pipes, and thermoplastic elements. It also governs crack width control in reinforced concrete structures and is used to evaluate tensile stresses in cross-sections of segmental concrete bridges.

The loading combinations applied in this study are as follows:

Combination 1

Self-weight (MS)	: 1,30
Additional Dead Load (MA)	: 2,00
Lane Load (TD)	: 1,80
Earth Pressure (TA)	: 1,25
Pedestrian Load (TP)	: 1,00

The design of the Box Culvert Segment was carried out using the ultimate strength method (ultimate design) and Serviceability Limit State (SLS 1). Figure 4 illustrates the external forces acting on the Box Culvert Segment

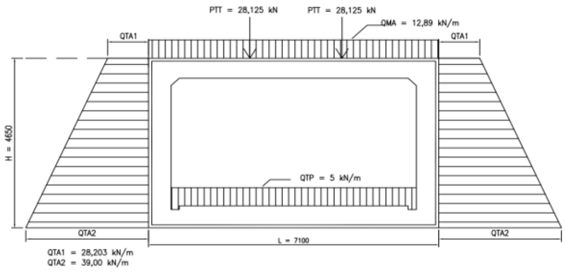


Figure-4. Sketch of External Forces Acting on the Box Culvert Segment

The structure of the Box Culvert tunnel segment was modeled as a two-dimensional box with several boundary conditions to determine the most critical internal force requirement among the applied conditions. The boundary conditions applied are as follows:

1. The soil beneath the tunnel was modeled as a spring with a vertical spring constant value based on the guidelines of the Ministry of Public Works and Housing (PUPR) in the *Technical Bridge Design Manual* [12]. In this study, a value of 48,000 kN/m³/m was adopted.
2. Each corner of the tunnel was assigned a hinge support.

Based on the structural analysis conducted, the tunnel structure with hinged support at each corner resulted in the highest internal force demand. Therefore, the reinforcement design in this study was based on Boundary Condition 2 and Load Combination 1. Table 2 summarizes the reinforcement details of the Box Culvert Segment.

Table-2. Summary of Reinforcement for Box Culvert Segment

`Slab	Direction	Reinforcement	
		Support	Span

Top	Short	D22 – 100	D22 – 100
	Long	D16 - 100	D16 - 100
Bottom	Short	D22 – 200	D22 – 200
	Long	D16 – 200	D16 – 200
Wall	Short	D22 – 100	D22 – 200
	Long	D16 - 100	D16 – 200

C. Estimation of Jacking Force for Box Tunnel Installation

The jacking force required for the Box Tunnel was estimated under construction conditions with a 1.0 m soil cover above the box. The jacking force was calculated by considering the frictional forces on all sides of the box [13]. Soil parameters were divided into three layers, and the calculation was performed for a total jacking length of 42.4 m.

The jacking process of pushing the Box Tunnel into the soil results in the mobilization of soil resistance. Therefore, it is necessary to analyze the soil resistance around the Box Tunnel while accounting for the loads acting upon it. To reduce soil resistance, all walls of the Box Tunnel were coated with an anti-drag system (ADS). The ADS is analyzed as follows:

ADS Material =*Zynclaume Sheet Steel*
Koef. Friksi (μ) $= tan\delta = tan(\varphi)$
$= tan(30) = 0{,}29$

The Anti-Drag System is lubricated with oil-based grease, which reduces the coefficient of friction by 70%.
Thus, the effective friction coefficient: (μ) = 30% × 0,29 = 0,087

1. **Roof Drag (RD)**
   RD = F1 (μ)
   F1 = Additional Dead Load
   = 12,89 kN
   μ = 0,087
   RD = 12,89. 0,088 =1,13432 kN

2. ***Wall Drag* (WD)**
   WD = F2 × 2
   (μ') = 30% × $tan(17)$ = 0,0494
   F2 = Frictional force due to earth pressure
   F2 = Frictional force due to earth pressure
   = [{(P1 + P2) × μ' × h1)} + {(P3+ P4) × μ × h2)}] × Panjang Dinding
   = ((24,16 × 0,0494 × 2) + (33,943 × 0,087× 2)) × 10,3 =105,701 kN

   There are two wall sides on the box tunnel; therefore, the wall drag value is multiplied by two.

3. ***Floor Drag* (FD)**
   Floor drag = F.μ
   FD = F3 (μ)
   F3 = Additional Dead Load + Self-weight of box
   F3 = 12,89 + 31461,26
   FD = 31461,26 × 0,088 = 2768,6 kN

4. ***Face Load* (FL)**
   FL = Earth Pressure Load × Width of Box Tunnel
   FL = 12,89 × 7,1
   FL = 413,2413 kN

5. ***Jacking Force* (JF)**
   JF = RD + WD + FD + FL
   JF = 1,134 + 2768,6 + 211,402 + 412,53
   = 3393,658 kN
   To calculate the *Reduced Jacking Load*:
   Reduced Jacking Load = $\frac{JF \times SF}{0{,}9}$
   Where:
   SF = 1,3
   Efficiency of hydraulic jack = 0,9
   Reduced Jacking Load = $\frac{3393{,}658 \times 1{,}3}{0{,}9}$
   4901,951 kN

The capacity of a single hydraulic jack is 400 tons, and an additional spacer is required to push one Box Culvert Segment, weighing 52 tons [13]. Therefore, the number of hydraulic jacks required per segment is:

Hydraulic *Jack* = $\frac{4901{,}951 \times 10^{-1} ton + 52 ton}{400 ton}$

$$=1{,}35 = 2\ jacks$$

Based on the above planning analysis, the jacking force required to install one Box Culvert Segment is approximately 4,901.95 kN. To insert one segment, two hydraulic jacks with a maximum capacity of 400 tons each are required. For each additional Box Culvert Segment, an additional jacking force of 4,306.17 kN is needed. Therefore, to install all four Box Culvert Segments into the ground, a total jacking force of 17,820.17 kN is required, and a total of six hydraulic jacks (2 jacks × 3 operations) must be provided.

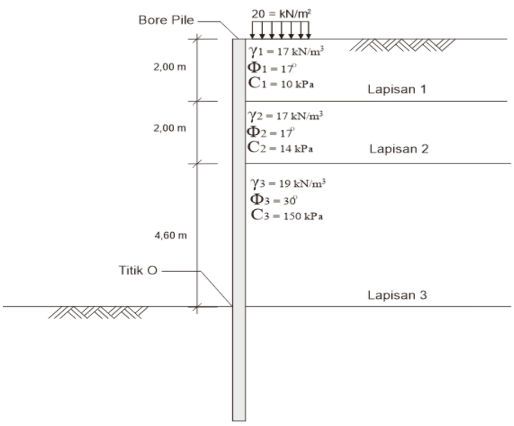
D. Structural Design of Retaining Structures for the Culvert Box Segment Work Area

The planned excavation depth determined for the project's working area—used for the fabrication and jacking of the Culvert Box Segment—is 7.6 meters below the original ground surface. Based on the existing site conditions and the project plan, load estimations required for the design of the bored piles were obtained. The bored piles are classified into three types, as each pile type is subjected to different loads, necessitating varied design specifications [14].

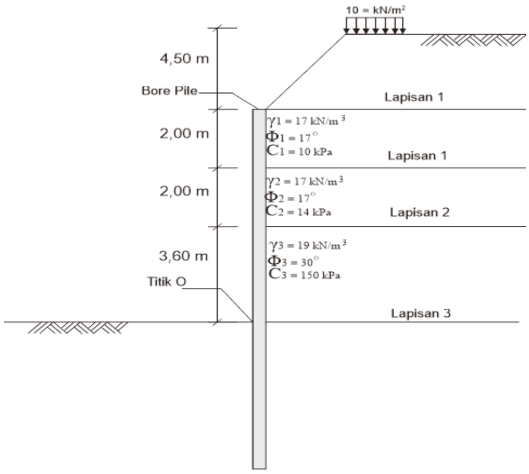
The bored pile design calculations consider both the excavation requirements and the acting loads. Excavation parameters were established in accordance with project conditions and data provided by PT Delta Systech Indonesia, as well as site observations [11]. The design criteria used in this bored pile planning include:

Concrete Strength	= Fc' 25 Mpa
Concrete Mod.	= E 23500 Mpa
Steel Yield Strength	= Fy 420 Mpa
Steel Mod.	= E 200000 Mpa

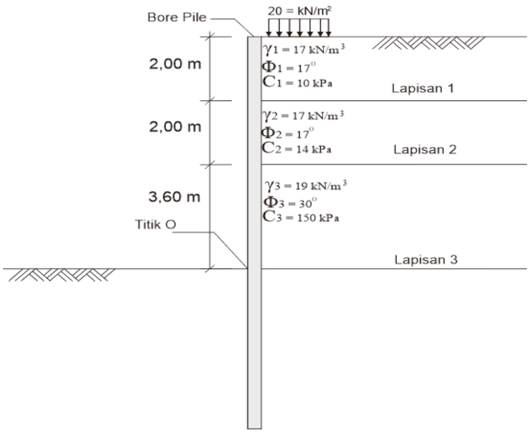
The excavation design for each type of bored pile is illustrated in Figure 5: (a) for BP1; (b) for BP2; and (c) for BP3.



(a)



(b)



(c)

Figure-5. Bored Pile Excavation Design: (a) BP1; (b) BP2; dan (c) BP3

Table 3 presents the excavation depth summary for each bored pile based on the soil layer stratification.

Table-3. Summary of Bored Pile Excavation Design

Name	Excavation Depth (m)	Layer 1 (m)	Layer 2 (m)	Layer 3 (m)
BP 1	8,6	2	2	4,6
BP 2	7,6	2	2	3,6
BP 3	7,6	2	2	3,6

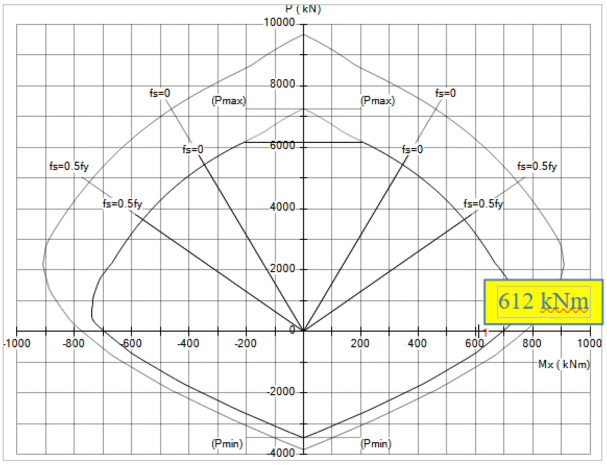
There is a slight variation in the load acting on Bored Pile 2, as it must resist the load of a 4.5-meter-high embankment for the toll road, as shown in the excavation plan for BP2 (Figure 5b). Subsequently, lateral and active earth pressures acting on each soil layer of the bored piles were calculated. These values were then used to determine the required depth of the bored piles. Table 4 summarizes the required bored pile depths

(D).

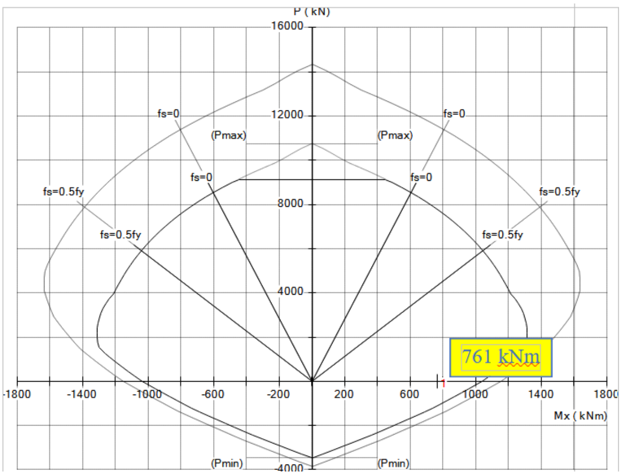
Table-4. Summary of Bored Pile Depth Calculations

Name	Pa (kN/m)	Z (m)	y (m)	D (m)
BP 1	307,13	1,67	2,29	2,96
BP 2	500,39	1,20	2,24	3,32
BP 3	263,33	1,27	2,02	2,41

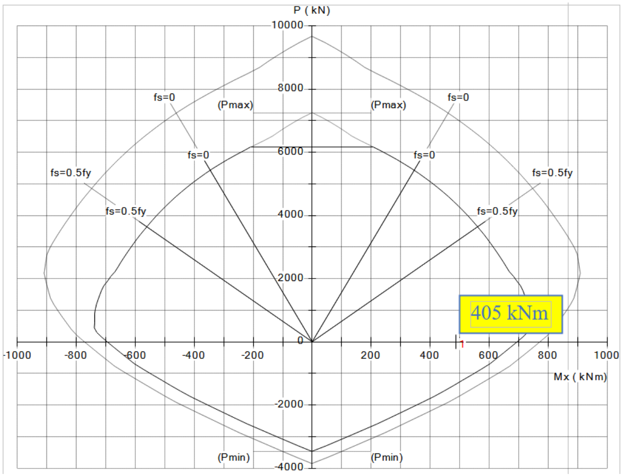
Next, the maximum bending moment (M_{max}) was calculated to assess the bored pile's section capacity, assisted by the SP Column software (trial version). The software was used to determine the moment capacity (ØM_n), which was then divided by the corresponding maximum moment for each pile. The ratio of ØM_n to M_{max} must exceed 1 to confirm that the pile can safely resist the applied forces. The interaction diagrams for each bored pile are shown in Figure 6: (a) BP1; (b) BP2; and (c) BP3.



(a)



(b)



(c)

Figure-6. Bored Pile Interaction Diagrams: (a) BP1; (b) BP2; dan (c) BP3

The results of the maximum moment and reduced moment calculations are summarized in Table 5.

Table 5. Summary of Maximum and Reduced Moment

Name	Mmax (kNm)	ØMn (kNm)	ØMn/Mmax
Bored Pile 1	612,0638	695,43	1,136
Bored Pile 2	761,87	1036,18	1,360
Bored Pile 3	405,191	695,43	1,716

To obtain the value of ØM_n, both flexural and shear reinforcements must be determined. These reinforcement values were also calculated during the section capacity analysis using SP Column. The resulting reinforcement required to ensure the bored piles can resist the acting loads is presented in Table 6.

Table 6. Summary of Bored Pile Reinforcement

Name	Bored Pile Diameter (mm)	Flexural Reinforcement	Shear Reinforcement
Bored Pile 1	600	18 - D25	D10 - 100
Bored Pile 2	800	18 - D25	D10 - 100
Bored Pile 3	600	18 - D25	D10 - 100

E. Capping Beam Structural Design

The capping beam is designed to resist deflection at the top of the bored piles. The design of the capping beam was conducted using SP Column software. The maximum active lateral earth pressure acting along the bored pile was simulated as acting at the top of the pile. The capping beam was designed for Bored Pile 2, which bears the highest risk, as it supports the load from the toll road abutment. The results of the capping beam design are presented below.

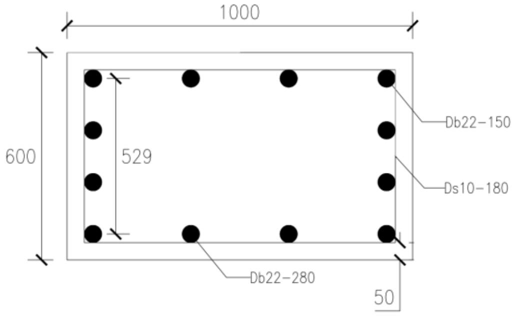


Figure 7. Cross Section of the Capping Beam

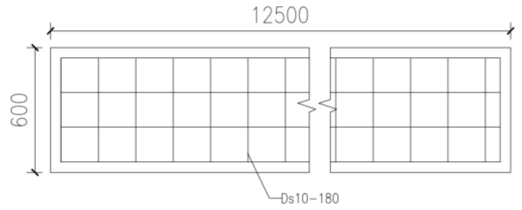


Figure 8. Longitudinal Section of the Capping Beam

Considering the varying consistency of soil layers [2], the tunnel construction site, which intersects with the toll road bridge and is located in a densely populated urban area [1], the Jacking Box Tunnel method was deemed the most suitable for constructing a pedestrian access tunnel connecting Jurang Mangu Station and BXC Mall. This method minimizes traffic disruption and reduces risks to surrounding structures.

IV. CONCLUSION

A. *Conclusion*

This study presents the analysis and planning of the Jacking Box Tunnel method, the design of Culvert Box segments, and the planning of the work area in the construction of a pedestrian access tunnel connecting Jurang Mangu Station and BXC Mall.

Based on the design results, the ultimate moment conditions in the Culvert Box segment structure are highest at the pinned supports located at both ends of the tunnel. A rebar diameter of 22 mm is required for the shorter span slab (7.1 m), while a diameter of 16 mm is required for the longer span slab (10.35 m). The jacking force required to push a single Culvert Box segment into the ground is calculated to be 4306.17 kN. A total of six hydraulic jacks are required to push all segments into position. With a safety factor of 1.3, the jacking load is considered sufficient to drive the segment boxes into the soil.

For the work area design, the required bored pile diameters are 600 mm for Bored Pile 1, 800 mm for Bored Pile 2, and 600 mm for Bored Pile 3, with 18D-25 for flexural reinforcement and 10D-100 for shear reinforcement across all pile types. Each bored pile is designed with a length of 12 meters. No deflection was observed at the pile heads due to the implementation of the capping beam.

With ØMn/Mmax values greater than 1, the bored piles are deemed capable of withstanding the loads imposed by vehicular traffic and heavy construction equipment during the construction phase.

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