Excavation method and support system in the diversion tunnel of Tiga Dihaji Dam, South Sumatera, Indonesia based on the rock mass quality

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Abstract. This study determined the excavation method and the support system in the diversion tunnel of Tiga Dihaji Dam, South Sumatera of Indonesia. Investigation performed in this study included surface geological mapping and evaluation of core drilling that are useful for determining rock mass quality. Geological conditions in the tunnel consist of tuffaceous sandstone lying unconformity over interbedded calcareous sandstone and calcareous siltstone. Based on the Geological Strength Index analysis, the excavation method for tuffaceous sandstone by hammer and blasting, and digging and ripping for the interbedded calcareous sandstone and calcareous siltstone. The support system is the installation of rock bolts of 3 m long with spaced 2.5 m on tuffaceous sandstone, 4 - 6 m long with spaced 1 - 1.5 m on interbedded calcareous sandstone and calcareous siltstone, and with shotcrete thickness of 50 - 200 mm (Rock Mass Rating). While in the Q-system classification were 2.7 m long rock bolts with spaced 2.7 m on tuffaceous sandstone, 2.7 m long rock bolts with spaced 1 – 2.4 m, and a shotcrete thickness of 25 cm on interbedded calcareous sandstone and calcareous siltstone.

1. Introduction
The tunnel is a construction that lies underground, built by excavation in a specific technique without disrupting the ground above. A tunnel forms an enclosed lane that connects two open sides or one open side with a particular purpose, such as roads, railways, mining access, or waterways [1]. Tunnel construction is one of the methods to protect the environment and support the principles of sustainable development.

In the excavation of tunnel openings, the tunnel's surrounding area's stability will be disturbed, leading to incidents such as landslides or collapse. The cause is due to changes in stress, where the stress conditions of rock mass were in equilibrium in the gravitational field before excavation. The transformation of the situation eventually causes deformation in a tunnel. The geological conditions influence this stability level in the area. Therefore, the selection of a suitable excavation method and support system is needed to overcome this problem.

In this study, the selection of excavation method and support system is determined based on the empirical method of rock mass classification, which identifies the parameters that affect rock behavior and dividing them into groups. The rock mass classifications used are Geological Strength Index (GSI) [2], Rock Mass Rating (RMR) [3], and Q-system [4].

2. Study location
The study location is in the diversion tunnel of Tiga Dihaji Dam, Sukabumi Village, Tiga Dihaji District, South Ogan Komering Ulu, South Sumatra Province of Indonesia (Figure 1). Based on the proposed design, the length of the diversion tunnel to be built is 595 m in the circle form with a 7 m of diameter.
The tunnel inlet is at 4°37'59.66" S and 103°52'35.39" E and the tunnel outlet is 4°37'32.09" S and 103°52'41.17" L.

3. Methodology
3.1. Observation of the surface geological condition
The surface geological conditions were observed directly on the outcrops at the study site. The observation covers the morphological and lithological conditions and geological structures, which are worthwhile for knowing the lithology of rocks at the research site and determine the presence of faults or joints in rock mass discontinuities.

3.2. Observation of the subsurface geological condition
Observation of subsurface geological conditions was carried out based on data from core drilling. The aim is to obtain the lithology and description of subsurface rocks according to the parameters in rock mass classification. There are three core drilling sample points located in the tunnel alignment (Figure 2). These observations calculated the quality of subsurface rock mass based on the GSI, RMR, and Q-system rock mass classifications.

4. Results and discussion
4.1. Surface geological condition
Based on Van Zuidam's classification [5], the research area has a varying slope, between 2 – 66°, with extremely steep slopes on riverbanks. The surface geological conditions identified tuffaceous sandstones of Ranau Formation [6] spreads unconformity over the interbedded calcareous sandstone and calcareous siltstone of Gumai Formation [6] (Figure 2 and 3). Tuffaceous sandstone (Figure 4, location on Figure 2) is a mixed pyroclastic-epiclastic with a young age from the results of carbon dating carried out by PT Virama Karya [7], which is 33 thousand years or the late Pleistocene. This very young age is a factor that causes rock formation in terms of weak adhesion between grains, causing rocks to decompose or be eroded by water quickly and make the condition in the study area to have steep river cliffs reaching 66°
with a height of more than 50 m. The river flow has wholly eroded the tuffaceous sandstone to the very bottom bordering the interbedded calcareous sandstone and calcareous siltstone.

Meanwhile, the interbedded calcareous sandstone and calcareous siltstone (Figure 5, location on Figure 2) consist of calcareous sandstone and calcareous siltstone with a thickness of 3 – 30 cm and a rock layer slope of up to 45° with a slope orientation towards the northeast (N308°E/44°). On the other hand, interbedded calcareous sandstone and calcareous siltstone are between the early and middle Miocene [6], where the age is very far from the tuffaceous sandstone. This thin layer causes the rocks to become brittle and weak between layering areas.

![Figure 3 Geological section A - B](image)

![Figure 4 Interbedded calcareous sandstone and calcareous siltstone at STA 9](image)

![Figure 5 Tuffaceous sandstone at STA 32](image)

4.2. Subsurface geological condition

Subsurface geological conditions were observed from three core drilling points on the tunnel alignment, namely DIV-1, DIV-2, and DIV-3, as shown in Figure 6.

- The DIV-1 drill point is at the tunnel inlet position, has a drilling depth of 65 m. The lithology is residual soil with a 0 – 2 m, highly to moderately weathered tuffaceous sandstone with a 3 – 6 m, and slightly weathered tuffaceous sandstone with a 7 – 65 m. The groundwater level is 10 m, and the tunnel is 46 – 54 m from the surface.

- The DIV-2 drill point is in the middle of tunnel alignment with a drilling depth of 60 m. The lithology in DIV-2 is residual soil with a 0 – 2 m, highly to moderately weathered tuffaceous sandstone with a 3 - 6 m, slightly weathered tuffaceous sandstone to a depth of 49 m, and below this is interbedded calcareous sandstone and calcareous siltstone. The tunnel is 43 – 51 m, with the tunnel floor located precisely at interbedded calcareous sandstone and calcareous siltstone. The groundwater level at this drill point is 10 m from the surface.

- The DIV-3 drill point is at the tunnel outlet with a drilling depth of 60 m. The lithology in DIV-3 is residual soil with a 0 – 1 m, highly – moderately weathered tuffaceous sandstone with a 2 - 7 m, slightly weathered tuffaceous sandstone to a depth of 44 m, and interbedded calcareous sandstone and calcareous siltstone with a 45 – 60 m. The tunnel is 45 - 52 m, with the roof of
the tunnel is the boundary between tuffaceous sandstone and interbedded calcareous sandstone and calcareous siltstone. The groundwater level is 17 m from the surface.

4.2.1 GSI

The GSI assessment is based on a direct description of core drilling results in the form of Rock Quality Designation (RQD) [8] and joint conditions [3]. The GSI assessment was carried out at each drill point and lithology, with results that obtained for GSI value of tuffaceous sandstone was between 15 – 87.5 (very poor – very good quality), and the GSI value for interbedded calcareous sandstone and calcareous siltstone was between 10.5 – 77.5 (very poor – very good quality). The results of the subsurface GSI assessment in the tunnel are summarized in Table 1.

| No. | Bore Hole | Lithology Unit | Depth    | Average GSI Score | Rating | Quality |
|-----|-----------|----------------|----------|-------------------|--------|---------|
| 1.  | DIV-1     | Tuffaceous sandstone | 3 - 65   | 78.98             | Very Good |
|     | DIV-1     | Tuffaceous sandstone | 3 - 49   | 75.59             | Good    |
|     | DIV-2     | Interbedded calcareous sandstone and calcareous siltstone | 50 - 60 | 10.50             | Very Poor |
| 2.  | DIV-2     | Tuffaceous sandstone | 2 - 44   | 66.74             | Good    |
|     | DIV-3     | Interbedded calcareous sandstone and calcareous siltstone | 45 - 60 | 36.97             | Poor    |

- At the DIV-1 drill point, the tuffaceous sandstone has the GSI value of 15 – 87.5 or very poor – very good quality, with an average RQD of 84.40 and joint conditions rating of 25. Therefore, to determine the excavation method at this point, the average GSI value is 78.98 or very good quality.
- At the DIV-2 drill point, the tuffaceous sandstone has the GSI value of 15 – 87.5 or very poor – very good quality, with an average RQD of 78.09 and joint conditions rating of 25. While in interbedded calcareous sandstone and calcareous siltstone, the GSI value of 10.50 or very poor quality, with an average RQD of 0 and joint conditions rating of 7. Therefore, the GSI value for determining the excavation method used for tuffaceous sandstone is 75.59 or good quality, and for interbedded calcareous sandstone and calcareous siltstone is 10.5 or very poor quality.
- At the DIV-3 drill point, the tuffaceous sandstone has the GSI value of 15 – 87.5 or very poor – very good quality, with an average RQD of 62.67 and joint conditions rating of 25. While in interbedded calcareous sandstone and calcareous siltstone, the GSI value of 10.50 – 77.50 or
very poor – very good quality, with an average RQD of 25.94 and joint conditions rating of 7 - 25. The GSI value for determining the excavation method used for tuffaceous sandstone is 66.74 or good quality, and for interbedded calcareous sandstone and calcareous siltstone is 36.97 or very poor.

4.2.2 RMR
Parameters in RMR assessment were obtained from direct observations of core drilling results, namely in RQD, discontinuity distance, discontinuity conditions, groundwater conditions, and joint orientation. In addition, the measurement of UCS value on the results of core drilling is also carried out. From the assessment results, the RMR values for tuffaceous sandstone are between 48 – 82 (fair – very good quality), and for interbedded calcareous sandstone and calcareous siltstone is between 17 – 56 (very poor – fair quality). The results of the RMR assessment at each drill point are summarized in Table 2.

| No. | Bore Hole | Lithology Unit | Depth  | Average RMR Score |
|-----|-----------|----------------|--------|-------------------|
|     |           |                |        | Rating | Quality |
| 1.  | DIV-1     | Tuffaceous sandstone | 3 - 65 | 69.46 | Good |
|     | DIV-2     | Tuffaceous sandstone | 3 - 49 | 68.81 | Good |
| 2   | DIV-2     | Interbedded calcareous sandstone and calcareous siltstone | 50 - 60 | 17 | Very Poor |
|     | DIV-3     | Tuffaceous sandstone | 2 - 44 | 67.69 | Good |
| 3   | DIV-3     | Interbedded calcareous sandstone and calcareous siltstone | 45 - 60 | 32.56 | Poor |

- At the DIV-1 drill point, the tuffaceous sandstone has an RMR value of 48 – 82 or fair – very good quality, with a UCS value of 5 – 25 MPa (rating 2), an average RQD of 84.40 (rating 17), a spacing of discontinuities of 2 m (rating 20), condition discontinuities slightly rough surface, small separation of 1mm and slightly weathered walls (rating 25), and the samples are dripping (rating 4). The average RMR value used in determining the excavation method and the support system used is 69.46 or good quality.
- At the DIV-2 drill point, the tuffaceous sandstone has an RMR value of 48 – 82 or fair – very good quality, with a UCS value of 5 – 25 MPa (rating 2), an average RQD of 78.09 (rating 17), spacing of discontinuities more than 2 m (rating 20), condition discontinuities slightly rough surface, small separation of 1mm and slightly weathered walls (rating 25), and the samples are dripping (rating 4). While in interbedded calcareous sandstone and calcareous siltstone, the RMR is 17 or very poor quality, with a UCS value of less than 1 MPa (rating 0), an RQD of less than 25 (rating 3), a small discontinuity spacing of 6 cm (rating 5), condition discontinuities slickenside surface (rating 7), and the samples are dripping (rating 4). To determine the excavation method and support system, the average RMR value of tuffaceous sandstone is 68.81 (good quality), and for interbedded calcareous sandstone and calcareous siltstone is 17 (very poor quality).
- At the DIV-3 drill point, the tuffaceous sandstone has an RMR value of 48 – 82 or fair – very good quality, with a UCS value of 5 – 25 MPa (rating 2), an average RQD of 62.67 (rating 13), spacing of discontinuities more than 2 m (rating 20), condition discontinuities slightly rough surface, small separation of 1mm and slightly weathered walls (rating 25), and the samples are dripping (rating 4). While in interbedded calcareous sandstone and calcareous siltstone, the RMR is 17 - 56 or very poor - fair quality, with a small UCS value of 0 - 25 MPa (rating 2-4), the average RQD is 25.94 (rating 3 - 17), the discontinuity spacing is 6 – 60 cm (rating 5 - 10),
condition discontinuities slightly rough surface - slickenside surface (rating 7 - 25), and the samples are dripping (rating 4). To determine the excavation method and the support system, the average RMR value of tuffaceous sandstone is 67.69 (good quality), and for interbedded calcareous sandstone and calcareous siltstone is 32.56 (poor quality).

4.2.3 Q-system

The parameters used in the Q-System assessment [4] are RQD, joint set number (Jn), joint roughness number (Jr), joint alteration number (Ja), joint water reduction factor (Jw), and stress reduction factor (SRF). From the observations, tuffaceous sandstone has a Q-system value of 5.9 - 60 (fair – very good quality), and interbedded calcareous sandstone and calcareous siltstone have a Q-system value of 0.001 – 35 (exceptionally poor – good quality). Q-system values at each drill point are summarized in Table 3.

Table 3 Summary of average Q-system score

| No.  | Bore Hole | Lithology Unit                          | Depth | Average Q-system Score | Rating | Quality |
|------|-----------|-----------------------------------------|-------|------------------------|--------|---------|
| 1.   | DIV-1     | Tuffaceous sandstone                    | 0 - 65| 34.26                  | Good   |         |
|      |           | Tuffaceous sandstone                    | 0 - 49| 32.48                  | Good   |         |
| 2.   | DIV-2     | Interbedded calcareous sandstone and    | 50 - 60| 0.001                 | Exceptionally poor |         |
|      |           | calcareous siltstone                    |       |                        |        |         |
|      |           | Tuffaceous sandstone                    | 0 - 44| 28.31                  | Good   |         |
| 3.   | DIV-3     | Interbedded calcareous sandstone and    | 45 - 60| 11.41                 | Good   |         |
|      |           | calcareous siltstone                    |       |                        |        |         |

- At the DIV-1 drill point, the tuffaceous sandstone has a Q-system value of 0.01 – 60 or exceptionally poor – very good quality, with an RQD value of 84.40, Jn is 1, Jr is 3, Ja is 1, Jw is 0.66, and SRF is 5. The average Q-system value used in determining the support system used is 34.26 or good quality.
- At the DIV-2 drill point, the tuffaceous sandstone has a Q-system value of 0.01 – 60 or exceptionally poor – very good quality, with an RQD value of 78.09, Jn is 1, Jr is 3, Ja is 1, Jw is 0.66, and SRF is 5. While in interbedded calcareous sandstone and calcareous siltstone, the Q-system is 0.001 or exceptionally poor quality due to the core results being destroyed during extraction and causing the RQD value to be 0. Therefore, to determine the support system at this drill point, the average Q-system value of tuffaceous sandstone is 32.48 (good quality), and for interbedded calcareous sandstone and calcareous siltstone is 0.001 (exceptionally poor quality).
- At the DIV-3 drill point, the tuffaceous sandstone has a Q-system value of 0.01 – 60 or exceptionally poor – very good quality, with an RQD value of 62.67, Jn is 1, Jr is 3, Ja is 1, Jw is 0.66, and SRF is 5. While in interbedded calcareous sandstone and calcareous siltstone, Q-system value is between 0.001 – 35 or exceptionally poor - good quality, with an RQD value of 25.938, Jn is 3, Jr is 3, Ja is 0.8, Jw is 0.66, and SRF is 2. To determine the support system at this drill point, the average Q-system value of tuffaceous sandstone is 28.31 (good quality), and for interbedded calcareous sandstone and calcareous siltstone is 11.41 (good quality).

4.3 Excavation Method

Determination of the most efficient excavation method to be used is done empirically using a graph of the GSI value and the Is50 value [9]. The GSI value has been obtained in the previous discussion, while the Is50 value is the point load value of the rock mass. The point load value is obtained based on the conversion of the UCS test results on the sample. The point load value for tuffaceous sandstone is 0.31
– 1.50 MPa, and interbedded calcareous sandstone and calcareous siltstone is 0 – 0.59 MPa, so use the graph Is50 value less than 3 MPa. The RMR classification can also determine the excavation method according to the type of rock. The excavation method for tuffaceous sandstone can be performed by hammer and blasting, full face with an excavation rate of 1.0 - 1.5 m. Meanwhile, the interbedded calcareous sandstone and calcareous siltstone at the DIV-2 drill point can be performed by digging, multiple drifts, and excavation rate of 0.5 – 1.5 m and, the DIV-3 drill point can be performed by ripping, benching with an excavation rate of 1 - 1.5 m. The results of the determination of the excavation method at each drill point are shown in Table 4.

### Table 4 Summary of excavation methods based on GSI and RMR classification

| No. | Bore Hole | Lithology Unit | Excavation Methods |
|-----|-----------|----------------|--------------------|
| 1.  | DIV-1     | Tuffaceous sandstone | Blasting          |
|     |           | Tuffaceous sandstone | Blasting          |
|     |           | Interbedded calcareous sandstone and calcareous siltstone | Blasting          |
|     |           | Tuffaceous sandstone | Full face with 1–1.5 m advance |
|     |           | Interbedded calcareous sandstone and calcareous siltstone | Full face with 1–1.5 m advance |
| 2.  | DIV-2     | Interbedded calcareous sandstone and calcareous siltstone | Digging           |
|     |           | Tuffaceous sandstone | Multiple drifts with 0.5–1.5 m advance in the top heading |
|     |           | Interbedded calcareous sandstone and calcareous siltstone | Hammer            |
|     |           | Tuffaceous sandstone | Full face with 1–1.5 m advance |
| 3.  | DIV-3     | Interbedded calcareous sandstone and calcareous siltstone | Ripping           |
|     |           | Tuffaceous sandstone | Top heading and bench with 1–1.5 m advance in the top heading |

### 4.4 Support System

An empirical method is determining support system type in the tunnel using rock mass classification RMR and Q-System. The support system based on RMR rock mass classification can be directly used from the RMR value, while Q-system classification can use the Q-system graph from the Norwegian Geotechnical Institute [9]. Other parameters in the Q-System to determine the type of support system are tunnel height and ESR value [10]. For example, the tunnel height at the research site is 7 m, and the ESR value used is 1. The results of the determination of the support system at each drill point are summarized in Table 5.

### Table 5 Summary of support systems based on RMR and Q-system classification

| No. | Bore Hole | Lithology Unit | Support Systems | RMR | Q-System |
|-----|-----------|----------------|-----------------|-----|----------|
| 1.  | DIV-1     | Tuffaceous sandstone | Rock Bolts      | 3 m long and spaced 2.5 m, occasional wire mesh | Unsupported or spot bolting with 2.7 m long, spaced 2.7 m |
|     |           |                 | Shotcrete       | 50 mm in the crown if required | none |
|     |           |                 | Steel Sets      | None | none |
|     |           |                 | Locally bolts in the crown | None | |
| 2.  | DIV-2     | Tuffaceous sandstone | Rock Bolts      | 3 m long and spaced 2.5 m, occasional wire mesh | Unsupported or spot bolting with 2.7 m long, spaced 2.7 m |
|     |           |                 | Shotcrete       | 50 mm in the crown if required | none |
5. Conclusion

The diversion tunnel of the Tiga Dihaji Dam was located in the lithology unit, namely tuffaceous sandstone and interbedded calcareous sandstone and calcareous siltstone. The rock mass classifications used in this study are GSI, RMR, and Q-system, and observed at three drilling points. At the DIV-1 drill point, the entire tunnel is in tuffaceous sandstone, at the DIV-2 drill point, the tunnel floor is between tuffaceous sandstone boundary and interbedded calcareous sandstone and calcareous siltstone, and at the DIV-3 drill point, the boundary between the tuffaceous sandstone and interbedded calcareous sandstone and calcareous siltstone is located on the roof of the tunnel. Classification of rock mass in tuffaceous sandstone has a quality of good – very good (GSI), good (RMR), and good (Q-system). Meanwhile, rock mass classification in interbedded calcareous sandstone and calcareous siltstone has very poor – poor (GSI and RMR) quality and good – exceptionally poor quality (Q-system).

Based on the results of GSI and RMR rock mass classifications, the excavation method is obtained in the form of a hammer and blasting on tuffaceous sandstone with an excavation rate of 1.0 - 1.5 m and...
interbedded calcareous sandstone and calcareous siltstone carried out by digging and ripping at a rate of 0.5 - 1.0 m. Tunnel support systems based on RMR classification on tuffaceous sandstone used bolts with a length of 3 m, spaced 2.5 m, and additional shotcrete with a thickness of 50 mm. In interbedded calcareous sandstone and calcareous siltstone, rock bolts are required with a length of 4 - 6 m, spaced 1 - 1.5 m, shotcrete with a thickness of 100 - 200 mm, and steel supports spaced 0.75 - 1.5 m. Meanwhile, according to Q-system classification, the support system for tuffaceous sandstone is in the form of spot bolting with a length of 2.7 m and a distance of 2.7 m. For interbedded calcareous sandstone and calcareous siltstone, a support system in the form of rock bolts with a length of 2.7 m, spaced 1 – 2.4 m is required, and cast concrete lining >25 cm in weak parts.

Further research is needed to support the implementation of this tunnel construction by performing numerical analysis to consider using the safe support system.

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