Pavement Design of Coal Mine Hauling Road in Indonesia using California Bearing Ratio (CBR) data

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Abstract. Mine activities in the open-pit method are usually dominated by digging-loading-hauling. This hauling road is the infrastructures that is highly essential in mine area and serve as main linkage some locations. Design of the road requires careful attend in avoidance of failure in construction and disruption in production activities. Field investigations such as insitu CBR testing and laboratory testing (Proctor Modified and CBR laboratory) were chosen to determine the geotechnical parameters of soils that needed in the design of hauling road. The average value of the laboratory CBR testing at 0.1 inch penetration was 16%. The modified type of proctor test comprise some parameters such as the average value of the maximum dry density was 1.64 gr/cm³; the maximum wet density was 1.97 gr/cm³; the average value of dry unit weight was 16.07 kN/m³; saturated unit weight was 19.30 kN/m³; optimum moisture content was 20.2%. The average value of insitu CBR testing at 0.1 inch penetration was 19%. The average load of tire pressures on the front and rear wheels is 7000 lbs. The ability of road to carry the load should have the bearing capacity $\geq 20800$ psf = 144.44 psi = 20.95 kPa. The thickness of each pavement layer is as follows: 17 inches of sub grade layer; 2 inches of subbase course layer; 15 inches of base course layer; 5 inches of surface course layer.

1. Introduction

In an open-pit method, the hauling road became an essential part of the mining activities. Those activities comprise digging, hauling, and loading things. Digging always do by excavate or blast soil or rock material in the overburden layer with an aim to open the covering layer and then excavate the valuable deposits for further extraction. The overburden materials is loaded into the dump truck and brought to the disposal area, while the deposit material are delivered to the stockpile, crusher, processing facilities or jetty. The extraction of deposits usually consist of mineral, coal or other valuable materials.

This type of road has became the important infrastructure in mining activities. It perform function as a connection among important locations such as pit/quarry – crusher – stockpile/room – processing plant – jetty and another locations. The design of the road required serious attempt so that the road do not encounter failure in construction that can affect production stage. The aspect that need to be considered is road pavement design. This aspect could not be separated from the issue of the bearing capacity of soil, the dimension and type of dump trucks or vehicles that pass through the road. Field investigations and soil sampling in the sub-base layer need to be carried out to determine the geotechnical characteristics of the determined mine hauling route. Both field CBR and laboratory soil
testing were chosen to support this design project. The investigations underlie on the location of the proposed hauling road that belongs to the coal mining company of PT. X as appear in Figure 1 below. It was part of Loa Janan Area, Kutai Kartanegara District of East Kalimantan Province.

Figure 1. Locations of geotechnical investigations

This paper address the results of investigation aimed at obtaining geotechnical parameters in support of the design of road pavement at the location of the proposed mine hauling route in PT. X. The parameters is required to determine the bearing capacity of the road to burden the loads which derives from the dump trucks or other vehicles that move across the road especially the tire pressure generated from the them, and also to calculate the thickness of the pavement layer beneath the road surface. It is also needed to check if the existing design suitable and sufficiently strong to burden the load of the tire pressure.

Some studies related to CBR and their applications in pavement design of the hauling road have been carried out in several locations. Demara, et. al (2019), conducted an evaluation of the hauling road for the nickel mine in the Fatufia District of Morowali, Central Sulawesi Province. Noorraya, et. al (2019) design a hauling road for coal mine in Tapin District, South Kalimantan. Kurniawan, et. Al (2019), conducted an evaluation of the hauling road by considering the influence of the road geometric design on the fuel consumption and productivity.

2. Field CBR Testing
Field CBR testing is another type of CBR test that conduct insitu. This testing determine the CBR number by comparing the penetration load of the piston into soil against the value of the penetration load of standard material. Moreover, it also include the evaluation of the quality of subgrade, sub base and base course layers. During the test, the penetration force would be recorded for each penetration stage. A curve of stress-penetration relationship would be figured and CBR number is determined by using this curve. Procedures of testing was conducted by referring to SNI 1738-2011 and ASTM D-4429-10. The sketch of field CBR apparatus could be seen in Figure 2.1 below.
3. Laboratory Soil Testing
This testing was performed in the laboratory. It consist of Proctor Modified test and CBR laboratory test. The test was conducted on samples taken from the location of the proposed mine hauling road. Procedure of Proctor Modified test was conducted by referring to SNI 1743-2008 or ASTM D-1557-10, while procedure of CBR test referred to SNI 1744-2012 or ASTM D-1883-10.

3.1. Proctor Modified Test
The purpose of the test is to know the behaviour of soil when the compaction energy was given to it. For each compaction energy, the density depends on the amount of water within the soil, termed as water content. If the water content low, the soil is hard or stiff that makes it difficult to compact. If the water content is increased, the soil is easily to compact because the water will act as a lubricant within the soil. At higher water content, the density will decrease as the pores of the soil become full of water and can no longer be compacted.

Figure 3.1. Proctor test modified type (Das & Sobhan, 2018)
This test is conducted to achieve the optimum moisture content and maximum dry unit weight of a compaction process. The maximum dry unit weight unit ($\gamma_{d\,\text{max}}$) is the peak value of unit weight achieved in the Proctor test by giving adequate energy. Optimum water content ($w_{\text{opt}}$) is the number of water content that resulted from giving adequate compaction energy to reach dry unit weight ($\gamma_{d\,\text{max}}$). The figure and sketch of the Modified Proctor apparatus can be seen in Figure 3.1. The compaction energy per unit volume can be given as:

$$E = \frac{\left(\frac{\text{Number of blows per layer}}{\text{of layers}}\right) \times \left(\frac{\text{Weight of hammer}}{\text{drop of hammer}}\right)}{\text{Volume of mold}}$$

Specifications of Modified Proctor Compaction Test is given in Table 3.1 below.

| Item                | Procedure | A               | B               | C               |
|---------------------|-----------|-----------------|-----------------|-----------------|
| Mold diameter       | 4 in. (101.6 mm) | 4 in. (101.6 mm) | 6 in. (152.4 mm) |
| Volume of mold      | 0.0333 ft$^3$ (944 cm$^3$) | 0.0333 ft$^3$ (944 cm$^3$) | 0.075 ft$^3$ (2124 cm$^3$) |
| Weight of hammer    | 44.5 N (10 lb) | 44.5 N (10 lb) | 44.5 N (10 lb) |
| Height of drop      | 457 mm (18 in.) | 457 mm (18 in.) | 457 mm (18 in.) |
| No.of soil layer    | 5          | 5               | 5               |
| No.of blows/layer   | 25         | 25              | 56              |
| Energy of compaction| 56,250 ft lb/ft$^3$ (27000 kN-m/m$^3$) | 56,250 ft lb/ft$^3$ (27000 kN-m/m$^3$) | 56,250 ft lb/ft$^3$ (27000 kN-m/m$^3$) |
| Material            | Passing No. 4 sieve | Passing 9.5 mm (3/8 in.) sieve | Passing 19 mm (3/4 in.) sieve |

3.2. California Bearing Ratio (CBR) Test

California Bearing Ratio (CBR) is the ratio of the penetration resistance of piston which is loaded into soil against the penetration resistance of piston loaded into standard sample which derives from split gravel of California. The number of ratio took at penetration of 2.5 and 5.0 mm (0.1 and 0.2 in.) with the usage of the highest of both numbers. The penetration resistance of soil is the force needed to retain the penetration of piston which loaded into soil. This testing is conducted to assess the strength of compacted soil in the laboratory which later is used in the pavement design. The sketch of laboratory CBR testing equipment is given in Figure 3.2. The range value of CBR in determining types of soil is given in Table 3.2. The empirical curve of CBR that determine the thickness of pavement layer using CBR numbers, wheel loads, and the type of material layers is given in Figure 3.3.
Figure 3.2. Sketch of laboratory CBR apparatus (Sukirman, 2010).

Table 3.2. Range value of CBR numbers.

| General Soil Type | USC Soil Type | CBR Range |
|-------------------|---------------|-----------|
|                   | GW            | 40 – 80   |
|                   | GP            | 30 – 60   |
|                   | GM            | 20 – 60   |
| Coarse-grained soils | GC          | 20 – 40   |
|                   | SW            | 20 – 40   |
|                   | SP            | 10 – 40   |
|                   | SM            | 10 – 40   |
|                   | SC            | 5 – 20    |
| Fine-grained soils | ML           | 15 or less |
|                   | CL LL < 50 %  | 15 or less |
|                   | OL            | 5 or less  |
|                   | MH            | 15 or less |
|                   | CL LL > 50 %  | 10 or less |
|                   | OH            | 5 or less  |
Figure 3.3. Empirical curve of flexible pavement in determining the thickness of layer (Terzaghi, 1996).

3.3. Bearing Capacity Formula
Road bearing capacity is the ability of the road to burden the load that comes from vehicles. Determination of the bearing capacity of road can be done by a soil mechanic engineer. Information about geotechnical properties of various types of soils is needed to calculate the bearing capacity. For the design of hauling road, the bearing capacity is quantified based on the amount of load distributed through the tire.

The distribution of load on the wheels can be calculated as given:

\[
\text{Load distribution} (lb/\text{in}^2) = \frac{\text{load work on wheel (lb)}}{\text{bearing area (in}^2)}
\]

\[
\text{Load distribution} (lb/\text{in}^2) = \frac{0.9 \times \text{load work on wheel (lb)}}{\text{tire pressure (psi)}}
\]

4. Results and Discussion
The research investigations produced outputs derives from field and laboratory testings such as field CBR, Proctor Modified and CBR laboratory. Then, these outputs are used to calculate the bearing capacity of road and also the thickness of the pavement layers. Based on the information available, the type of dump truck that will be used in mine operation is the HINO truck 500 FM 260 series. Specification relate to the truck will be input on the pavement design.
4.1. Results of Field CBR Testing
Field testing has been done along the location of the proposed hauling route. Summary of the results will be given on Table 4.1 as follow.

| Test No. | Penetration (inch) | Load (lbs) | CBR Value (load/std.load) (%) | Average CBR Value (%) |
|----------|--------------------|------------|-------------------------------|-----------------------|
|          | 0.1                | 374.31     | 12.48                         | 15.30                 |
|          | 0.2                | 543.52     | 18.12                         |                       |
| CBR-01   |                    |            |                               |                       |
|          | 0.1                | 112.81     | 3.76                          | 3.93                  |
|          | 0.2                | 123.06     | 4.10                          |                       |
| CBR-02   |                    |            |                               |                       |
|          | 0.1                | 153.83     | 5.13                          | 6.07                  |
|          | 0.2                | 210.23     | 7.01                          |                       |
| CBR-03   |                    |            |                               |                       |
|          | 0.1                | 558.53     | 18.62                         | 19.28                 |
|          | 0.2                | 598.43     | 19.95                         |                       |
| CBR-04   |                    |            |                               |                       |
|          | 0.1                | 598.43     | 19.95                         | 21.19                 |
|          | 0.2                | 673.23     | 22.44                         |                       |
| CBR-05   |                    |            |                               |                       |
|          | 0.1                | 1221.79    | 40.73                         | 43.30                 |
|          | 0.2                | 1376.38    | 45.88                         |                       |
| CBR-06   |                    |            |                               |                       |
|          | 0.1                | 698.17     | 23.27                         | 32.41                 |
|          | 0.2                | 1246.73    | 41.56                         |                       |
| CBR-07   |                    |            |                               |                       |
|          | 0.1                | 847.77     | 28.26                         | 42.39                 |
|          | 0.2                | 1695.55    | 56.52                         |                       |
| CBR-08   |                    |            |                               |                       |
|          | 0.1                | 997.38     | 33.25                         | 41.56                 |
|          | 0.2                | 1496.07    | 49.87                         |                       |
| CBR-09   |                    |            |                               |                       |
|          | 0.1                | 748.04     | 24.93                         | 29.09                 |
|          | 0.2                | 997.38     | 33.25                         |                       |
| CBR-10   |                    |            |                               |                       |
|          | 0.1                | 174.54     | 5.82                          | 7.48                  |
|          | 0.2                | 274.28     | 9.14                          |                       |
| CBR-11   |                    |            |                               |                       |
|          | 0.1                | 274.28     | 9.14                          | 11.64                 |
|          | 0.2                | 423.89     | 14.13                         |                       |
| Average  | 0.1                | 18.78      |                               |                       |
|          | 0.2                | 26.83      |                               |                       |

4.2. Results of Laboratory Testing
Laboratory testing has been carried out on samples taken from hauling route. It comprised Proctor Modified and CBR laboratory. Summary of the results will be given on Table 4.2 and Table 4.3 as follows.
Table 4.2. Summary of results from Proctor Modified Testing

| Sample Code | Max. Density | Unit Weight | Optimum Moisture |
|-------------|--------------|-------------|------------------|
|             | Dry (gr/cm³) | Wet (kN/m³) | Content (%)      |
|             | Dry          | Wet         |                  |
| CBR Lab-01  | 1.61         | 1.95        | 15.78            | 19.09 | 21.0 |
| CBR Lab-02  | 1.63         | 1.97        | 15.97            | 19.33 | 21.0 |
| CBR Lab-03  | 1.63         | 1.96        | 15.97            | 19.17 | 20.0 |
| CBR Lab-04  | 1.54         | 1.91        | 15.09            | 18.71 | 24.0 |
| CBR Lab-05  | 1.79         | 2.06        | 17.54            | 20.17 | 15.0 |
| Average     | 1.64         | 1.97        | 16.07            | 19.30 | 20.2 |
| Min         | 1.79         | 2.06        | 16.07            | 19.30 | 20.2 |
| Max         | 1.54         | 1.91        | 15.09            | 18.71 | 15.0 |

Table 4.3. Summary of results from CBR Laboratory Testing

| Test No. | Penetration (inch) | Jumlah Pukulan | Beban Bawah | Beban Atas | Beban Rerata | CBR Value | Ave. CBR Value |
|----------|--------------------|----------------|-------------|------------|--------------|-----------|----------------|
|          |                    | 10 ×           | 355.49      | 355.49     | 355.49       | 10.00     | 11.56          |
|          |                    | 25 ×           | 381.64      | 428.69     | 405.16       | 10.67     | 19.67          |
|          |                    | 56 ×           | 507.12      | 431.31     | 431.31       | 14.00     |
| CBR-01   | 0.1                | 10 ×           | 507.12      | 575.08     | 541.10       | 17.00     |
|          |                    | 25 ×           | 522.79      | 643.04     | 582.92       | 18.33     |
|          |                    | 56 ×           | 648.28      | 585.54     | 585.54       | 23.67     |
|          | 0.2                | 10 ×           | 507.12      | 334.58     | 841.71       | 13.67     |
|          |                    | 25 ×           | 637.83      | 507.12     | 572.48       | 17.00     |
|          |                    | 56 ×           | 711.00      | 666.57     | 666.57       | 19.00     |
|          | 0.1                | 10 ×           | 627.35      | 460.07     | 543.71       | 23.33     |
|          |                    | 25 ×           | 784.20      | 679.64     | 731.92       | 29.00     |
|          |                    | 56 ×           | 993.34      | 831.26     | 1101.15      | 31.67     |
|          | 0.2                | 10 ×           | 480.98      | 428.69     | 454.83       | 13.33     |
|          |                    | 25 ×           | 810.35      | 705.79     | 758.07       | 22.00     |
|          |                    | 56 ×           | 1208.96     | 993.34     | 1101.15      | 33.33     |
| CBR-02   | 0.1                | 10 ×           | 643.04      | 611.68     | 627.36       | 23.00     |
|          |                    | 25 ×           | 993.34      | 935.81     | 964.58       | 36.67     |
|          |                    | 56 ×           | 1498.71     | 1393.80    | 1393.80      | 54.00     |
|          | 0.2                | 10 ×           | 418.23      | 303.22     | 360.73       | 11.67     |
|          |                    | 25 ×           | 533.25      | 439.14     | 486.19       | 14.00     |
|          |                    | 56 ×           | 663.95      | 598.60     | 598.60       | 17.33     |
|          | 0.1                | 10 ×           | 522.79      | 381.64     | 452.21       | 19.33     |
|          |                    | 25 ×           | 637.83      | 606.44     | 622.14       | 23.67     |
|          |                    | 56 ×           | 841.71      | 776.36     | 776.36       | 29.67     |
| CBR-04   | 0.2                | 10 ×           | 559.39      | 334.58     | 446.99       | 15.67     |
|          |                    | 25 ×           | 988.10      | 637.83     | 812.97       | 27.00     |
|          |                    | 56 ×           | 1154.01     | 1065.83    | 1065.83      | 32.00     |
| CBR-05   | 0.1                | 10 ×           | 742.39      | 517.58     | 629.98       | 26.67     |
|          |                    | 25 ×           | 1268.91     | 951.50     | 1110.21      | 46.67     |
|          |                    | 56 ×           | 1538.68     | 1453.75    | 1453.75      | 55.00     |
|          | 0.2                |                |             |            |              |           |
| Average  | 0.1                | 16.20          |
|          | 0.2                | 27.29          |
4.3. Bearing Capacity of Road

Bearing capacity of road is determined based on the load distribution of vehicle on each wheel. It can be seen from the specification data, termed as tire pressure, issued by the manufacturer of dump truck. HINO dump truck 500 FM 260 series is selected as operational dump truck. The calculation of bearing capacity of road will be given as follow.

Conversion factors: $1 \text{ kg} = 2.204 \text{ lb}, 1 \text{ psi} = 144 \text{ psf} = 6.895 \text{ KPa}$

Front tire:
- Load on wheel axis (full charged) = 5500 kg (12125 lbs)
- Number of tire $= 2$
- Tire pressure $= 100 \text{ psi}$

Based on the data, load on each wheel given as:

$$= \frac{12125 \text{ lbs}}{2} = 6062.5 \text{ lbs}$$

- Contact area (inch$^2$)
  $$= \frac{0.9 \times 6062.5 \text{ lbs}}{100 \text{ psi}} = 54.563 \text{ inch}^2$$

- Load work on road
  $$= \frac{6062.5 \text{ lbs}}{54.563 \text{ in}^2} = 111.11 \text{ psi} = 16000 \text{ psf}$$

Rear tire:
- Load on wheel axis (full charged) = 20000 kg (44092 lbs)
- Number of tire $= 8$ (comprise of 4 set double tire)
- Tire pressure $= 100 \text{ psi}$
- Equivalent load number of single tire $= 1.2$

Based on the data, load on each wheel given as:

$$= \frac{44092 \text{ lbs}}{8} = 5511.5 \text{ lbs}$$

Because rear tire are double, the load of each tire must be multiplied by the equivalent load number of single tire as given below:

- Equivalent load of each tire $= 1.2 \times 5511.5 \text{ lbs} = 6613.8 \text{ lbs}$
- Contact area (inch$^2$)
  $$= \frac{0.9 \times 6613.8 \text{ lbs}}{100 \text{ psi}} = 59.524 \text{ inch}^2$$

- Load work on road
  $$= \frac{6613.8 \text{ lbs}}{59.524 \text{ in}^2} = 111.111 \text{ psi} = 16000 \text{ psf}$$

By the same calculation as above (variation of pressures: 110, 120 and 130 psi), a summary of calculation of the load work on the road given in Table 4.4. Based on the value, the bearing capacity of road should be equivalent or more than 20800 psf $= 144.44 \text{ psi} = 20.95 \text{ KPa}$ to burden the load from vehicle without failure.

| Tire Pressure (psi) | Contact Area (inch$^2$) | Load Work on Road (psf) |
|---------------------|-------------------------|-------------------------|
|                     | Front Tire | Rear Tire | Front Tire | Rear Tire | Average Value |
| 100                 | 54.563     | 59.524    | 16000      | 16000     | 16000         |
| 110                 | 49.602     | 54.113    | 17600      | 17600     | 17600         |
| 120                 | 45.468     | 49.603    | 19200      | 19200     | 19200         |
| 130                 | 41.971     | 45.787    | 20800      | 20800     | 20800         |
4.4. Pavement Design Using CBR Data

The type of pavement that will be used in the design of hauling road is flexible pavement. It comprise sub-grade, sub-base course, base course and surface course layer. The configuration of each layer in a flexible pavement can be seen in Figure 4.1 as follow.

![Figure 4.1. Configuration of layer in flexible pavement.](image)

The design of mine hauling road is a development of former transportation road of timber log that exist on the area. Both of field and laboratory CBR value used in the design, especially for calculating the thickness of each layer. The field CBR value will be assumed as the CBR value of base course layer. The CBR value of sub-grade layer will be derived from the value of laboratory CBR. It is because sampels taken from this layer was examined by CBR testing in the laboratory. The CBR value of surface course layer will be resulted by examining aggregate or split rock materials with CBR testing in the laboratory. It is better to use the materials that available around or near the location of hauling road. Then, both of the CBR value of each pavement layer and empirical curve of Figure 3.3 will be utilized in calculating the thickness of each layer.

Based on Table 4.3, the average value of laboratory CBR on 0.1 inch penetration of piston is obtained as of 16.20 % ≈ 16 %. The number is the CBR value of sub-grade layer. According to information on sub chapter 4.3, the load work on front and rear wheel is 6062.5 and 6613.8 lbs. Then, the average load will become 7000 lbs. Both of the CBR value of 16 % and the average load of 7000 lbs will be plotted into Figure 3.3 to calculate the thickness of pavement layer and the thickness is obtained as of 17 inch. The pavement above the sub-grade layer will be designed 17 inch in thickness.

Based on Table 4.1, the average value of field CBR on 0.1 inch penetration of piston is obtained as of 18.78 % ≈ 19 %. The number is the CBR value of base course layer of the former timber log road. To predict the thickness of this layer, both of the CBR value of 19 % and the average load of 7000 lbs will be plotted again into Figure 3.3 and the thickness is obtained as of 15 inch. The value of 15 inch will be measured from the surface. So, the thickness of sub-base course layer will be calculated as follow: (17− 15) inch = 2 inch.

The result of CBR testing on aggregate or split rock materials in the laboratory is 85 %. The material will be used in designing of the surface course layer. To predict the thickness of this layer, both of the CBR value of 85 % and the average load of 7000 lbs will be plotted again into Figure 3.3 and the thickness is obtained as of 5 inch. Then, this layer will be designed 5 inch in thickness by using aggregate or split rock materials on the surface. The summary of calculation on thickness of each pavement layer will be given on Table 4.5 as follow.

**Table 4.5. Summary of the thickness layer calculation.**

| Layers            | Type of material       | CBR (%) | Thickness Layer (inch) |
|-------------------|------------------------|---------|------------------------|
| Surface course    | Aggregate, split rock  | 85      | 5                      |
| Base course       | Clay                   | 19      | 15                     |
| Sub-base course   | Clay                   | 19      | 2                      |
| Sub-grade         | Clay                   | 16      | 17                     |
5. Conclusion
This investigation gives some conclusions as follows:

- The average value of CBR laboratory testing obtain as of 16 % on 0.1 inch penetration of piston
- Proctor Modified testing gives some parameters as follow: the average value of maximum dry density as of 1.64 gr/cm$^3$, maximum wet density as of 1.97 gr/cm$^3$; the average value of dry unit weight as of 16.07 kN/m$^3$, wet unit weight as of 19.30 kN/m$^3$, optimum moisture content as of 20.20 %.
- The average value of field CBR testing obtained as of 19 % on 0.1 inch penetration of piston
- The average load of tire pressure that work on both front and rear wheel obtained as of 7000 lbs
- The ability of road to burden that load must have the bearing capacity equivalent or more than 20800 psf = 144.44 psi = 20.95 kPa
- The thickness of each pavement layer given as follow: the sub-grade layer as of 17 inch, sub-base course layer as of 2 inch, base course layer as of 15 inch, and surface course layer as of 5 inch.

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