ANALYSIS OF THE INFLUENCE OF SOIL BEARING CAPACITY ON THE SELECTION OF MECHANICAL EQUIPMENT IN COAL MINING OPERATIONS AT THE ALAM 8-9 AREA OF PT MUARA ALAM SEJAHTERA.

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ABSTRACT: This study aims to analyze the soil bearing capacity and its effect on the selection of mechanical equipment in coal mining at Area Alam 8-9 PT Muara Alam Sejahtera. The *dynamic cone penetrometer* (DCP) test was applied to obtain the *california bearing ratio* (CBR), which was then converted into soil bearing capacity. In addition, *ground pressure* (GP) analysis of the mechanical equipment was conducted. The results show that the average soil bearing capacity values for the three segments were 7,61 kg/cm² (pit road), 5,26 kg/cm² (disposal area), and 5,13 kg/cm² (original soil). The highest GP value was recorded for the *heavy dump truc*k CMT 106 at 6,54 kg/cm². The comparison between DDT and GP indicates that the pit road segment was adequate to support all equipment, while the disposal and original soil segments are not recommended for HD CMT 106 and CMT 96 due to potential failure. This study highlights the need for road improvement in low bearing capacity areas to ensure safer and more efficient operations.

Keywords: *soil bearing capacity*, CBR, *ground pressure*, mechanical equipment, coal mining.

1. Pendahuluan

Coal mining activities require the support of mechanical equipment to ensure smooth operational performance. Heavy equipment such as excavators, bulldozers, and dump trucks plays a crucial role in supporting productivity, efficiency, and workplace safety. The effectiveness of these machines is not only determined by their capacity and technical specifications but is also strongly influenced by the conditions of the working environment, particularly soil characteristics. One of the key factors that must be considered is the soil bearing capacity, which refers to the ability of the soil to withstand the loads applied to it. Maintaining a balance between soil bearing capacity and ground pressure is essential for optimizing the performance of heavy equipment. If the soil bearing capacity is lower than the equipment's ground pressure, the machines may experience reduced mobility or even the risk of sinking [1]. Therefore, the selection of mechanical equipment should not be based solely on operational capacity but must also take into account the soil's ability to support the imposed loads.

In practice, each type of heavy equipment has different operational loads, requiring appropriate equipment selection based on the soil bearing capacity at the mining site. Forcing equipment to operate on soil that cannot adequately support its load can negatively affect the continuity of mining operations. Hence, soil bearing capacity analysis becomes a critical initial step in planning and making operational decisions in the field.

The Alam 8–9 area of PT Muara Alam Sejahtera is one of the sites undergoing mine expansion. Currently, the area is in the early phase of land clearing and has not yet undergone surface preparation or soil reinforcement. This condition necessitates an analysis to determine the extent to which the soil can support the loads of mechanical equipment planned for use, such as excavators, bulldozers, and dump trucks. By analyzing soil bearing capacity, the selection of equipment type and capacity can be adjusted to the existing soil conditions, ensuring that mining operations can proceed optimally and safely.

1.1 *California Bearing Ratio (CBR)*

California bearing ratio (CBR) is a value obtained from the comparison between the penetration load on material and the penetration load on a standard ma measured at the same depth and penetration rate.

comparison is expressed as a percentage, representing the soil's bearing capacity against applied loads. The CBR test can be conducted using three different methods, one of which is the field CBR test utilizing the *Dynamic Cone Penetrometer* (DCP). Through DCP testing, data on soil bearing strength can be obtained up to a depth of 90 cm from the subgrade surface. The results of this test are typically expressed in two parameters: the Penetrometer Penetrability Scale (SPP), measured in mm/blow, and the Soil Penetration Rate (SPR), measured in blow/mm. Based on the correlation between DCP test results and CBR values, George F. Sowers and William F. Hedges introduced an equation in 1950 to convert DCP data into CBR values [2].

$$DPI = \frac{\Delta d}{N} \quad (1)$$

$$CBR = 10^{(2,56-1,16x(Log(DPI)))} \quad (2)$$

Description:

CBR	= Bearing capacity value of the tested material (%)
DPI	= Penetration depth per blow (mm/blow)
Δd	= Penetration depth for one hammer blow (mm)
N	= Number of hammer blows

1.2 *Dynamic Cone Penetrometer*

Dynamic Cone Penetrometer (DCP) is an instrument equipped with a steel cone tip with a diameter of 20 mm and cone angles of 30 degrees and 60 degrees, which is driven into the soil to a specified depth. The device is fitted with an 8 kg sliding hammer and a vertical scale to facilitate reading of the penetration depth for each blow, as illustrated in Figure 1. The DCP is used to measure the California Bearing Ratio (CBR) value of soils and to evaluate the strength of pavement layers.

DCP testing measures the penetration depth of the cone after receiving impact from the sliding hammer. Each blow produces a different penetration depth. The DCP method can be used to determine subgrade depth and directly calculate the CBR value in the field. This test provides accurate information regarding the soil's bearing capacity within pavement layers and allows for rapid assessment of subgrade and base-layer strength [3].

The use of the *Dynamic Cone Penetrometer* (DCP) for determining the *California Bearing Ratio* (CBR) value has several advantages. First, this method is relatively economical, reducing the cost of field testing. Second, DCP testing is non-destructive, meaning it does not damage the subgrade surface being evaluated. Third, data collection with this tool can be performed in a relatively short time, making it efficient in terms of test duration. However, there are also some limitations to using the DCP. The instrument cannot be applied to very hard surface layers such as rock, concrete, or asphalt, as doing so may damage the equipment. Additionally, the DCP cannot directly measure soil moisture content or density; therefore, the test results do not provide a comprehensive description of the soil's physical condition. The Dynamic Cone Penetrometer instrument is shown in Figure 1 below [4].

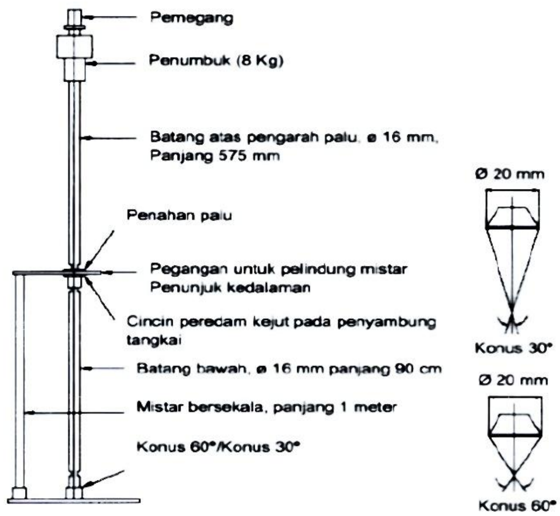

Figure 1. dynamic cone penetrometer

1.3 Soil Bearing Capacity

Soil is a loose material derived from the weathering process of rocks, either physically or chemically. Soil contains voids known as pores, which are filled with air and water. Weathered material that remains in its original location is referred to as residual soil, whereas material that has been transported from its source area is known as transported or alluvial soil [5].

Soil bearing capacity is the ability of the soil to withstand loads or pressures applied to its surface without experiencing failure. In the context of mining activities, soil bearing capacity is an essential aspect because it is directly related to the operational stability of heavy mechanical equipment operating on the ground surface. The assessment of soil bearing strength is generally carried out using the California Bearing Ratio (CBR) value. The CBR value indicates the magnitude of the soil's load-bearing capacity; the higher the CBR value, the greater the soil's ability to support loads above it [6]. Heavy equipment exerts loads on the soil, while the soil provides resistance in the form of "bearing capacity." Therefore, the pressure exerted by heavy equipment on the soil must be lower than the soil's bearing capacity [7].

One of the commonly used methods to evaluate subgrade strength is by measuring the California Bearing Ratio (CBR) value. This CBR value can be used direct... calculations through empirical formulas or by utili... correlation diagrams between CBR values and soil bea...

capacity (DDT). Such correlations are typically performed by drawing reference lines based on CBR values obtained from laboratory or field testing.

According to Indonesianto [8], to determine the soil bearing capacity (DDT) on haul roads, one may use the formula developed by the United States Army Engineer (USAE) as follows:

$$DDT = (4{,}3592 \log CBR) + 1{,}6649 \quad (3)$$

1.4 *Ground Pressure*

Ground pressure is the pressure exerted by mechanical equipment on the ground surface. In planning the selection of mechanical equipment for mining activities, it is essential to determine the magnitude of the ground pressure that will be applied to the soil. In the process of designing haul roads, the first step that can be taken is to identify the maximum load of the heaviest equipment operating in the area [9].

The equation used to determine the magnitude of the pressure exerted by a haulage vehicle on the ground, or ground pressure (GP), can be expressed as follows [10]:

$$GP = \frac{\text{Vehicle Weight (empty +loaded)}}{\text{n x Contact Area of Tires Touching the Ground}} \quad (4)$$

2. Research Method

The research was conducted at PT Muara Alam Sejahtera, located in Merapi Barat District, Lahat Regency, from May 5, 2025 to June 17, 2025.

The research stages began with a literature study, followed by field observation, data collection, and subsequently data processing and analysis. The data used in this study consist of primary and secondary data. The primary data include Dynamic Cone Penetrometer (DCP) test results obtained directly from the field at 33 test points, as well as the contact area data of several mechanical equipment units collected on-site. Meanwhile, the secondary data consist of maps of the sampling locations and the specification data of the mechanical equipment used in the field.

The obtained data were processed using manual calculations based on theoretical references derived from the literature study. Data processing was carried out using Microsoft Excel 2019. After processing, the data were analyzed and evaluated according to the objectives of the study. The following outlines the detailed process of data processing and analysis:

1. The DCP test results obtained from three segments namely the pit area, the Alam 8–9 disposal area, and the original ground area of Alam 8–9 are converted into California Bearing Ratio (CBR) values using the equations developed by George F. Sowers and William F. Hedges (Equation 1 and Equation 2), adjusted for the use of a 60° cone. The resulting CBR values are then used to calculate soil bearing capacity using Equation 3. This data processing step is performed using Microsoft Excel.
2. The field observation data and the specification data of mechanical equipment operating in the Alam 8–9 area are used to calculate the ground pressure values using Equation 4. These ground pressure values serve as the minimum soil bearing capacity required to support the mechanical equipment operating within the study area.
3. The ground pressure values and the soil bearing capacity values along the haul road are compared to determine whether the equipment units used in the area meet the required bearing capacity. The data are processed by comparing both values to identify which equipment units are capable or not capable of traversing the area.

3. Results and Discussion

Soil Bearing Capacity Values in the Alam 8–9 Area

The data collection segments for the CBR measurement using the Dynamic Cone Penetrometer are shown in Figure 2 and consist of three segments. The first segment is located on the haul road of Pit Alam 8–9, the second segment is located in the disposal area of Alam 8–9, and the third segment is located in the original Soil area of Alam 8–9. A total of 33 test points were evaluated in the Alam 8–9 area, with 14 points in Segment 1, 9 points in Segment 2, and 10 points in Segment 3.

Figure 2. Data collection points using DCP

The results obtained include the DPI values, which are subsequently converted into CBR values. After the CBR value for each test point is obtained, these values are then used to determine the soil bearing capacity in the haul road, disposal area, and original ground area of Alam

3.1 Bearing Capacity Values in Segment 1

In Segment 1, testing was conducted using the Dynamic Cone Penetrometer (DCP) at a total of 14 sampling points. The obtained CBR values were converted into soil bearing capacity values using Equation 3. Based on Table 1, the average soil bearing capacity value in Segment 1 was found to be 7.61 kg/cm².

Table 1. Bearing Capacity Values Segment 1

X and Y Coordinates	CBR (%)	Bearing Capacity (kg/cm^2)	Average Bearing Capacity (kg/cm^2)
354050.656E 9583055.701N	14,82	6,76	
354018.084E 9583079.089N	20,50	7,37	
354039.057E 9583092.280N	33,30	8,20	
354026.383E 9583027.139N	13,96	6,51	
354157.694E 9583074.545N	14,32	6,66	
353948.804E 9583060.301N	31,03	8,14	
353946.140E 9583061.511N	48,07	8,90	
353962.786E 9583067.171N	37,50	8,50	7,61
353963.785E 9583071.157N	18,48	7,17	
353972.890E 9583071.171N	9,21	5,84	
353979.688E 9583056.919N	35,76	8,38	
353992.442E 9583069.431N	24,32	7,64	
354002.347E 9583057.509N	28,85	7,96	
354014.670E 9583058.630N	41,83	8,52	

3.2 Bearing Capacity Values in Segment 2

In the area of segment 2, testing was carried out using the Dynamic Cone Penetrometer (DCP) at 9 testing points. The CBR values obtained were converted into soil bearing capacity values using Equation 3. Based on Table 2, the average soil bearing capacity value for segment 2 was 5.26 kg/cm².

Table 2. Bearing Capacity Values Segment 2

X and Y Coordinates	CBR (%)	Bearing Capacity (kg/cm^2)	Average Bearing Capacity (kg/cm^2)
354509.226E 9582993.040N	22,18	7,50	
354509.917E 9582979.214N	16,31	6,93	
354533.683E 9582979.806N	9,99	6,01	
354493.160E 9582967.475N	7,46	5,44	
354476.206E 9583017.975N	3,75	4,16	5,26
354457.017E 9583001.135N	4,30	4,42	
354515.409E 9582949.150N	4,29	4,32	
354534.754E 9582930.496N	4,00	4,29	
354497.550E 9582932.979N	4,05	4,31	

3.3 Bearing Capacity Values in Segment 3

In the area of segment 3, testing was conducted using the Dynamic Cone Penetrometer (DCP) at 10 testing points. The CBR values obtained were converted into soil bearing capacity values using Equation 3. Based on Table 3, the average soil bearing capacity value was 5.13 kg/cm².

Table 3. Nilai Daya Dukung Tanah Segmen 3

X and Y Coordinates	CBR (%)	Bearing Capacity (kg/cm^2)	Average Bearing Capacity (kg/cm^2)
354338.205E 9582764.240N	5,34	4,83	
354351.959E 9582773.333N	4,36	4,42	
354372.164E 9582777.562N	7,67	5,51	
354390.007E 9582804.233N	6,07	5,07	
354407.046E 9582777.058N	8,23	5,64	5,13
354415.332E 9582801.620N	6,03	5,06	
354423.730E 9582831.705N	4,29	4,32	
354437.094E 9582810.058N	4,00	4,29	
354434.365E 9582773.893N	5,62	4,90	
354419.914E 9582713.615N	7.62	5,41	

Table 4. CBR and Bearing Capacity Values in the Ala
8–9 Area

Segment	CBR (%)	Bearing Capacity (kg/cm^2)
Segment 1	26,57	7,61
Segment 2	8,48	5,26
Segment 3	6,43	5,13

Based on Table 4 above, the segment with the highest CBR and bearing capacity values is Segment 1, while the segment with the lowest CBR and bearing capacity values is Segment 3.

3.4 Ground Pressure Values of Mechanical Equipment in the Alam 8–9 Area

The soil bearing capacity and ground pressure are two interrelated parameters, particularly in the planning of haul roads and disposal areas. Ground pressure represents the load imposed on the soil, whereas the soil bearing capacity is the parameter that describes the ability of the soil to resist this ground pressure. The types of equipment for which ground pressure will be calculated are as follows: Hitachi ZX870H-5G Excavator, SDLG E6360F Excavator, Hitachi ZX350H-5G Excavator, Hitachi ZX200-5G Excavator, SDLG LG6210E Excavator, CMT 106 Heavy Dump Truck, CMT 96 Heavy Dump Truck, Dongfeng DFH3310A12 Dump Truck, Komatsu D375A-5 Bulldozer, and D375A-6R Bulldozer. The specification data for the excavators and bulldozers were obtained from the company and the respective equipment handbooks, while the contact area data for the tires of the CMT 106, CMT 96, and dump truck units were collected directly in the field.

Table 5. Ground pressure Mechanical Equipment

No	Type of Equipment (Loading Equipment)	Track Surface Area (cm²)	Equipment Weight (kg)	*Ground Pressure* (kg/cm^2)
1.	*Hitachi ZX870H-5G*	75.920	82.300	1,08
2.	*SDLG E6360F*	56880	37700	0,66
3.	*Hitachi ZX350H-5G*	55880	32900	0,59
4.	*Hitachi ZX200-5G*	50040	19800	0,40
5.	*SDLG LG6210E*	50040	20700	0,41

No	Type of Equipment (Loading Equipment)	Track Surface Area (cm²)	Equipment Weight (kg)	*Ground Pressure* (kg/cm^2)
1.	Heavy dump truck CMT 106	15.960	104.400	6,54
2.	Heavy dump truck CMT 96	15.960	96.000	6,01
3.	*Dump Truck DFH3310A 12*	9.600	31.000	3,22

No	Type of Equipment (Loading Equipment)	Track Surface Area (cm²)	Equipment Weight (kg)	*Ground Pressure* (kg/cm^2)
1.	*Komatsu D375A-5*	47.702	69.560	1,46
2.	*Komatsu D375A-6R*	48.556	71.640	1,48

Based on the calculations and the table presented above, the ground pressure of the HD CMT 106 is the highest among the equipment analyzed; therefore, it will serve as the reference for determining the minimum soil bearing capacity required for the mechanical equipment to traverse the area safely.

3.5 Comparison of Soil Bearing Capacity and Ground Pressure

After calculating the soil bearing capacity for segments one, two, and three, as well as determining the ground pressure of the equipment, the soil bearing capacity values of the three segments will be compared with the ground pressure of the mechanical equipment.

Table 6. Soil bearing capacity values for each segment compared to the equipment's ground pressure

Segment	DDT	*SDLG LG6210E*	*HD CMT 106*	*HD CMT 96*
1	7,61	0,41(✓)	6,54((✓)	6,01(✓)
2	5,26		6,54(✗)	6,01(✗)
3	5,13		6,54(✗)	6,01(✗)

Segment	Bearing Capacity	*DT DONGFENG DFH3310A12*	*Bulldozer komatsu D375A-5*	*Bulldozer Komatsu D375A-6R*
1	7,61	3,22(✓)	1,46(✓)	1,48(✓)
2	5,26			
3	5,13			

Segment	Bearing Capacity	*Hitachi ZX870H-5G*	*SDLG E6360F*	*Hitachi ZX350H-5G*	*Hitachi ZX200-5G*
1	7,61	1,08 (✓)	0,66 (✓)	0,59(✓)	0,4(✓)
2	5,26				
3	5,13				

Based on Table 6, which compares soil bearing capacity with the ground pressure of the equipment, it can be concluded that all mechanical equipment can operate in Segment 1. The reference for determining the minimum required soil bearing capacity is taken from the equipment with the highest ground pressure. The soil bearing capacity in Segments 2 and 3 is insufficient for several types of equipment. According to Table 6, all types of excavators are able to traverse all segments, and both bulldozers can also operate across all three segments. The Dongfeng dump truck can pass through every segment, however, the HD CMT 106 can only traverse Segment 1 and cannot operate in Segments 2 and 3. Similarly, the HD CMT 96 is limited to Segment 1 and is unable to traverse Segments 2 and 3

4.**Conclusion**

The soil bearing capacity values in Segment 1 (Alam 8–9 pit road), Segment 2 (disposal), and Segment 3 (original ground) are 7.61 kg/cm², 5.26 kg/cm², and 5.13 kg/cm², respectively. The ground pressure values for the mechanical equipment—Excavator Hitachi ZX870H-5G, Hitachi ZX200-5G, SDLG E6360F, SDLG LG6210E, and Hitachi ZX350H-5G—are 1.08 kg/cm², 0.40 kg/cm², 0.66 kg/cm², 0.41 kg/cm², and 0.59 kg/cm², respectively. Meanwhile, the ground pressure values for the mechanical equipment HD CMT 106, HD CMT 96, and Dongfeng DFH3310A12 are 6.54 kg/cm², 6.01 kg/cm², and 3.22 kg/cm², respectively. Additionally, the ground pressure values for the Bulldozer Komatsu D375A-5 and Komatsu D375A-6R are 1.46 kg/cm² and 1.48 kg/cm², respectively. A comparison between the soil bearing capacity values in Segments 1, 2, and 3 and the ground pressure of the mechanical equipment shows that all equipment can operate in Segment 1. However, in Segments 2 and 3, the use of HD CMT 106 and CMT 96 is not recommended due to the potential risk of ground failure. If the company intends to operate HD CMT 106 and CMT 96 in Segment 2 (disposal) or Segment 3 (original ground), it is advised to perform road improvement in these areas.

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