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IMPROVING BEARING CAPACITY USING TIRE-DERIVED-GEO-CYLINDER – A HAUL ROAD CASE STUDY IN JALAN SIKAR PENAJAM PASER

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ABSTRACT This paper showcases a potential solution to improve soil bearing capacity using tire-derived-geo-cylinder (TDGC). TDGC uses used tires to provide confining pressure and tensile strength, hence improving the soil's bearing capacity. The solution is applied for a haul road project on Jalan Sikar Penajam Paser. The site is frequently passed by large vehicles such as large trucks for the transportation of wooden logs and other heavy equipment. The tires used for TDGC are used tires of type LT245/75R16, which has a standard rim of 16 mm, a tire width of 248 mm, and an overall diameter of 780 mm. This category of tires has a load index of 1250-1600 kg. The load index is the value representing the tire's capacity to withstand load. The improvement in bearing capacity is evaluated using dynamic cone penetrometer (DCP) tests. In addition, the DCP tests were also used to interpret the Californian Bearing Ratio (CBR) values. The results show that without TDGC, the average CBR value is only 4.7%. In contrast, with TDGC, the average CBR increased to 17.2%, an increase of 265%. The CBR value obtained with TDGC places the soil into fair category for Subbase course. The average bearing capacity value obtained before TDGC was about 75 kN/m^2 and with TDGC, the soil experienced a significant increase in bearing capacity value to 245 kN/m^2. The increase of bearing capacity and CBR value from application of TDGC are due to the combination of the tires and stone fill. The tires provide tensile strength to resist lateral soil pressure as well as increased confining pressure, hence increasing the compressive strength.

KEYWORDS Haul road; Bearing capacity; Dynamic cone penetrometer; Tire-derived-geo-cylinder; Mechanical concrete

1 INTRODUCTION

In the mining or logging industry, a haul road is the road designed for heavy or bulk transfer of materials by haul trucks. Innovative soil improvements with varying techniques are continuously being developed, especially to improve subgrade foundation for roads. Soil improvement is one of the engineering methods to increase bearing capacity of soil. One category of soil improvement is by modifying the original soil condition with strong but economical materials.

An example of strong but economical materials are used tires. Used tires have high tensile and compressive strength, and they can be used to bind the aggregate of road foundation material, such as gravel and crushed stone. The tires provide circular confining pressure to the gravel/crushed stone placed inside it, thus increasing the compressive strength of gravel. The use of used tires as a method of soil improvement is called tire-derived-geo-cylinders (TDGC), also called mechanical concrete when it was first introduced by the U.S. Army Corps of Engineers in 1975.

In this paper, an application of TDGC for the site development and management of the industrial forest plantation sector in North Penajam Paser, East Kalimantan, Indonesia is presented. This location is often traversed by large trucks for the transportation of wooden logs and other heavy equipment. The project area is located on soft soil, and thus improvement of subgrade conditions in order for the trucks to transverse safely is required.

Figure 1. Wooden logs transportation activities in the study area

2 SITE DESCRIPTION

The project site is a state-owned acacia timber plantation which is managed by private companies for industrial plants. The project covers an area of 14,800 hectares, and the wooden logs are used for domestic production and export. The location of the timber plantation is in the Muara Toyu district, North Penajam Paser, East Kalimantan. Figure 2 shows the aerial photograph of the project site, as well as the research area.

Figure 2. Aerial photograph of the project site and research area

The transporting of acacia timber trees from the logging area to the harbor for water transportation requires the trucks to transverse across area with soft soil. To guarantee smooth transportation activities, good quality road with sufficient bearing capacity is needed. For this site, the haul road used is the typical unpaved road, only having a subgrade layer over the soft soil. Since the haul road is used for heavy logging transportation, the road bears high risk for bearing capacity failure. The risk of accident occurring is especially high during the rainy season.

3 RESEARCH METHOD

The research consists of several parts. Firstly, the aggregate class used for the fill for TDGC is determined. Secondly, the tires available for TDGC construction is identified. Thirdly, the arrangement of tires for TDGC is designed for. Finally dynamic cone penetrometer (DCP) tests were conducted before and after TDGC construction to evaluate the improvement in bearing capacity.

Determination of aggregate class is carried out by testing the toughness and abrasion resistance of aggregate with Los Angeles abrasion testing machine based on the Indonesian National Standards (SNI 2417:2018). Samples of the material tested are sand, stone 1/2", stone 2/3", and stone 3/4". This test includes selecting the appropriate amount of aggregate in accordance with the gradation required based on the technical specifications of the design. For aggregate Class A, the stone 3/4" is used, while for Class B, stone 2/3" is used.

The subgrade improvement technique adopted is tire-derived-geo-cylinder (TDGC) method, which is also known as mechanical concrete. The tires used are used tires of type LT245/75R16 (Figure 4). The tire has a standard rim of 16 mm, a tire width of 248 mm, and an overall diameter of 780 mm. The tire is of superior durability and has a load index of 1250-1600 kg. The load index is the value representing the tire's capacity to withstand load. This method is considered economical as the tires used come from waste tires of the logging trucks.

Tire Type and Size	LT245/75R16
Standard Rim	16 mm
Tire Width	248 mm
Overall Diameter	780 mm
Load Index (LI)	120/116 (1250-1600 kg)

Figure 3. Specifications of used tires used for TDGC

This soil improvement method is expected to increase the CBR value of soils with good conditions by up to 20% (Bowles, 1992). Figure 4 shows the design of TDGC. First, approximately 450 mm of existing soil is excavated. The subbase soil is then compacted with vibro roller. Thereafter, non-woven geotextile is lain above the subbase before placing 100 mm of class B aggregates. After compaction of class B aggregates, the used tires are then arranged in a grid pattern on the aggregate before being filled with class A aggregates. Finally, the TDGC are covered with class B aggregates to the final level and then compacted with vibro roller. The purpose of the TDGC is to distribute the load from heavy vehicles, reducing the pressure received by the soil underneath the TDGC (subbase), hence increasing the bearing capacity of the soil. Documentation of the construction sequence is shown in Table 1.

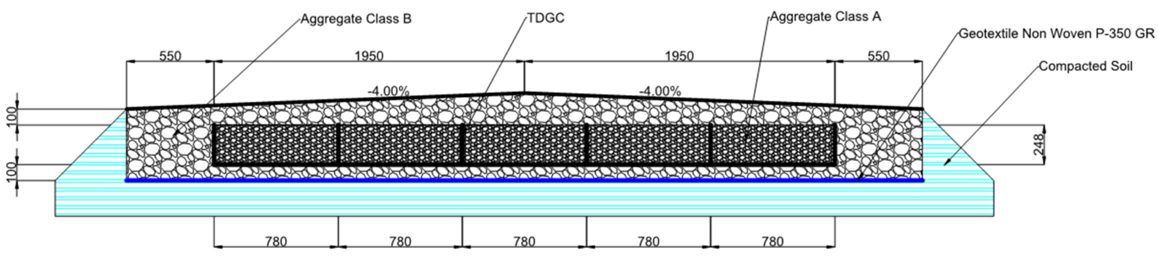


Figure 4. Design of the haul road with TDGC

To evaluate the bearing capacity, dynamic cone penetrometer (DCP) is used. Figure 5 shows the apparatus for DCP test. DCP test is a quick test to estimate the strength of subgrade and foundation layers. Based on the Surat Edaran Menteri Pekerjaan Umum No. 04/SE/M/3020 regarding the Application of the California Bearing Test Method Guidelines (2010), the CBR value can be calculated using the following correlation:

$$\text{Log10 (CBR)} = 2.8135\text{-}1.313 \text{ Log10 DCP} \quad (1)$$

Where DCP is the penetration rate in mm/blow. The DCP penetration rate has also been correlated with the bearing capacity of soils for founding structures. Paige-Green and Du Plessis (2009) suggest the value of bearing capacity can be determined as follow:

$$\text{Bearing Capacity (kPa)} = 3426.8 \text{ DCP}^{-1.0101} \quad (2)$$

As aforementioned, the DCP only provides an estimate for CBR value and bearing capacity and should not be used to replace conventional testing. However, if there is a limited time and budget, for low-risk project, DCP is a good alternative in-situ test method.

Table 1. Construction sequence of the tire-derived-geo-cylinders

No.	Sequences	Duration (days)	Documentations
1	Soil excavation	7	
2	Subbase compaction using vibro roller	14	
3	Installation of non-woven geotextile P-350 Gr	7	
4	Laying of class B aggregate for ground floor	5	
5	Ground compaction using vibro roller	7	
6	Installation of tires in grid pattern	5	

7	Filling of tires with class A aggregate	7	
8	Surface cover with class B aggregate, followed by compaction using Vibro Roller	7	

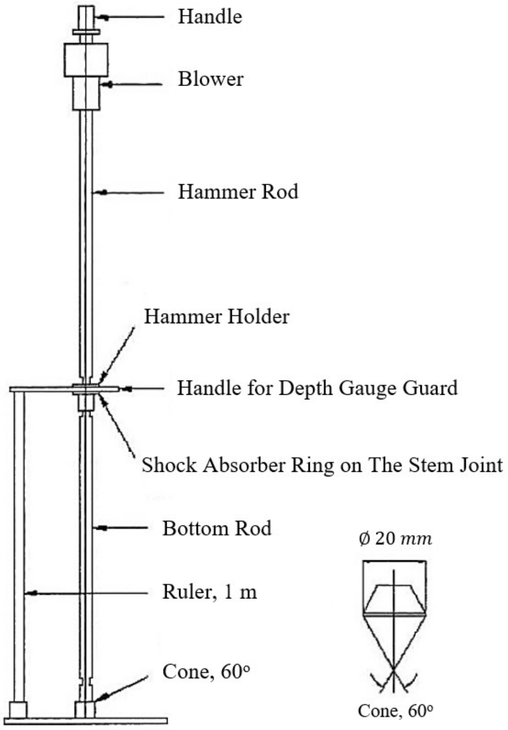
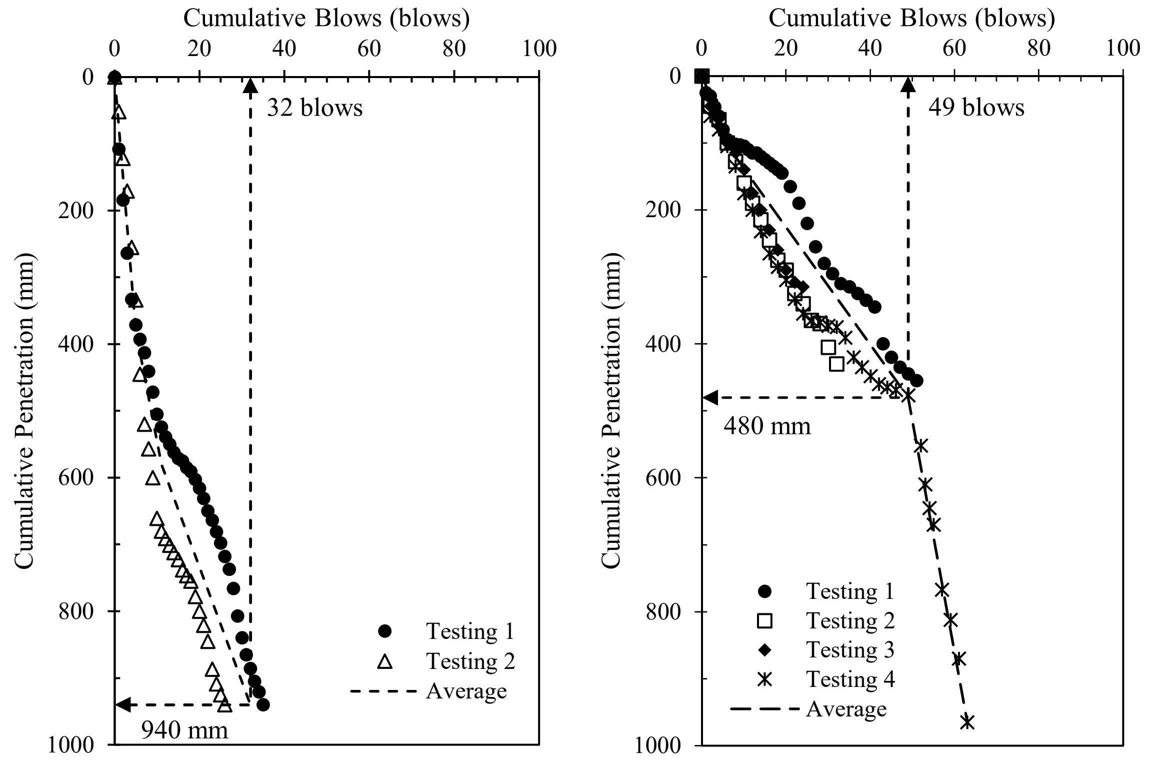


Figure 5. Dynamic cone penetrometer (DCP) apparatus with 60° cone

4 DCP TEST RESULTS

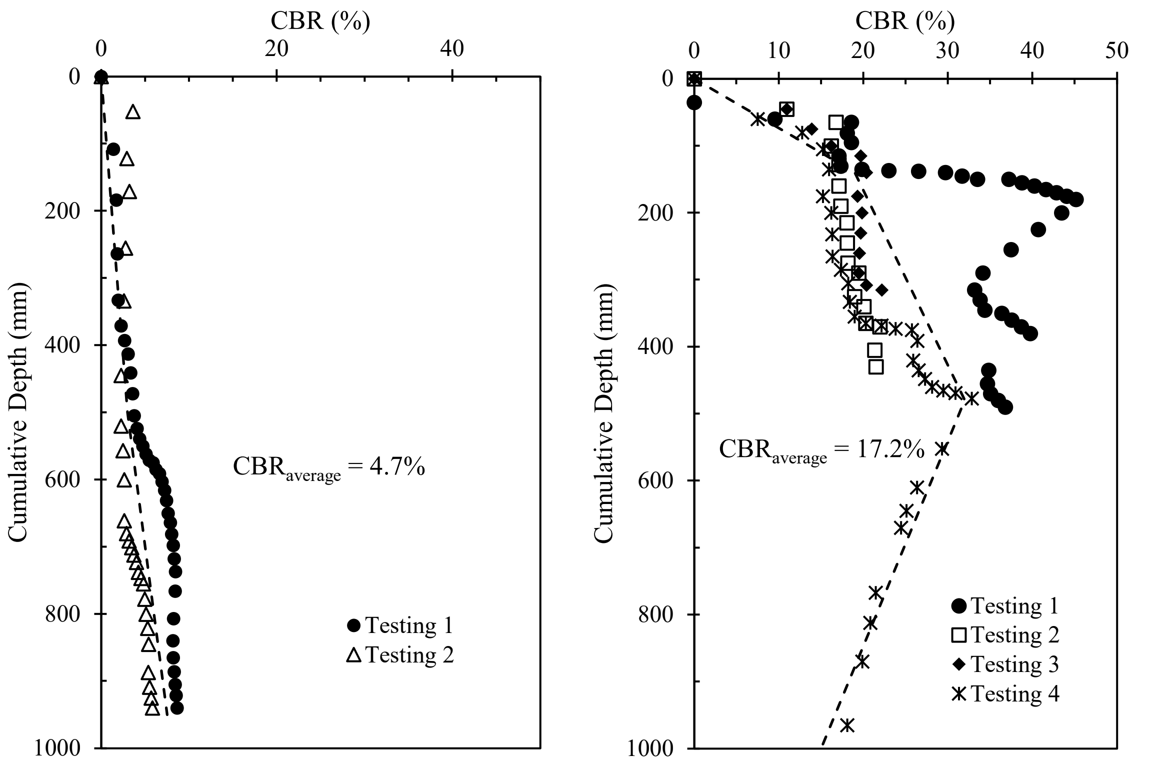
In this study, the bearing capacity values obtained from DCP tests before (prior to construction step 1 in Table 1) and after application of TDGC (after construction step 8 in Table 1) are compared. Two tests were conducted prior to construction, while four tests were conducted after construction. Fig. 6 shows the DCP test results (cumulative blow vs cumulative penetration). The DCP test results prior to construction of TDGC (Fig. 6a) shows an average value of 32 cumulative blows at the maximum penetration of 940 mm. After construction of TDGC (Fig. 6b), the average cumulative blows increased to 49 blows at a penetration depth of 480 mm. There is significant increase in blow count values for the first 500 mm due to the presence of aggregate as well as TDGC.

Fig. 7 shows the interpreted CBR values obtained from the DCP test results. There is a significant increase in the average CBR value, from 4.7% before construction of TDGC to 17.2% after construction of TDGC, an increase of 265%. According to Bowles classification (1992), shown in table 3, an average CBR value between 3-7% is considered as poor to the fair. Hence, prior to construction of TDGC, the soil conditions are not suitable to be used as a subbase course. In contrast, after construction of TDGC, the soil can be classified as fair, quite close to good category, making the soil suitable to be used as a subbase course.



(a) (b)

Fig. 6 DCP test results: (a) before construction of TDGC; (b) after construction of TDGC (average shown as dashed line)



(a) (b)

Figure. 7 Calculated CBR vs Depth: (a) before construction of TDGC; (b) after construction of TDGC (average shown as dashed line)

Table 3. Soil classification based on CBR value (Bowles, 1992)

CBR (%)	Level	Objective
0-3	Very Poor	Subgrade
3-7	Poor to Fair	Subgrade
7-20	Fair	Subbase
20-50	Good	Base or Subbase
>50	Excellent	Base

Table 4 shows the interpreted bearing capacity obtained from each test, as well as the average bearing capacity before construction of TDGC; while table 5 shows the same results after construction of TDGC. Before mechanical concrete, the interpreted bearing capacity was only 75 kN/m^2 and after construction of TDGC, the bearing capacity increases significantly to 245 kN/m^2.

The increase of bearing capacity and CBR values indicate that TDGC can improve compressive strength and also provides tensile strength to resist lateral soil pressure.

Table 4. Interpreted bearing capacity before construction of TDGC

Test No.	Bearing Capacity (kN/m^2)	Average (kN/m^2)
1	87.441	75.702
2	69.663	

Table 5. Interpreted bearing capacity after construction of TDGC

Test No.	Bearing Capacity (kN/m^2)	Average (kN/m^2)
1	329.915	245.082
2	206.453	
3	203.324	
4	240.636	

5 CONCLUSIONS

This research showcases the capability of tire-derived-geo-cylinder in improving CBR values and bearing capacity of soil. The following conclusions can be drawn from the test results:

1. The average DCP blow counts prior to construction of TDGC is 32 blows at the maximum penetration of 940 mm. Construction of TDGC increases the DCP blow counts to 48 blows at a penetration depth of 500 mm.
2. The CBR values interpreted from DCP tests show that the CBR values increases from 4.7% before the construction of TDGC to 17.2% after construction of TDGC. This means that the soil classification improves from ‘poor to fair’ category to ‘fair’ category.
3. The average bearing capacity value without TDGC was 75 kN/m^2 and experienced a significant increase to 245 kN/m^2 after construction of TDGC.

The increase in bearing capacity and CBR values indicates the suitability of TDGC in improving soil conditions for construction of haul road.

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