Design alternative on peat soil

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Abstract. Construction on peat soil has its own difficulty and challenge due to its properties of low shear strength, high compressibility, high water content, and flammable material. Indonesia ranked 4th on peat land area around the world after Canada, Russia, and United States. Based on recent mapping, peat land covers 14,9 million hectare in Indonesia. This paper presents the finding from literature studies regarding peat soil, construction on peat soil, case studies for road infrastructure construction on peat soil at West Borneo, Indonesia, and provide analysis and recommendation for the problems faced. Construction on peat soil requires special attention, especially on the design and execution. In the event where construction must be performed on a peatland which thickness is < 3m, the approach recommended is peat removal and replacement. If the peat thickness is 3-10 m, adopt the preloading, construction with vertical and sand drain, lightweight fills, surface mattress, stone column, etc. If the peat thickness is > 10m, use pile as foundation. Unit price contract is preferable over lumpsum contract due to the high uncertainties of peat soil. Environment impact due to construction on peat soil need to be accounted for, also the risk of peat fires need to be considered if dewatering used.

1. Introduction
Peat is found in many countries throughout the world and peatlands constitute about 3% of the land surface of the Earth. Indonesia ranked 4th on peat land around the world after Canada, Russia, and United States [1]. Recent study from 2013 shows estimation of Indonesia peat area around 14,9 million hectare, distributed at Sumatera, Borneo, and Papua region, which varies on the thickness from 1 to 10 meter averaging 3 meter thickness [2].

Peat is the accumulated remains of plant material, and it forms in growing peatlands (mires) where the activity of decomposing organisms is suppressed by waterlogging [3]. Peat is distinguished from other organic soil materials by its lower ash content (less than 25% ash by dry weight) [4]. Peat is often considered problematic for the construction due to its low shear strength, high compressibility and high water content. These characteristics lead to the problems and difficulties in the construction in various aspects such as pre-construction difficulty, post construction failures, cost of construction, maintenance issues, as well as short and long term impacts [5].

2. Peat Distribution
More than 95% of the total peatlands of the world are concentrated in the temperate climates of the Northern Hemisphere, which Canada and Russia having the greatest concentration of peatlands with a combined area of over 300 million ha. Peat also can be found in the tropical
climates, wherever the conditions are favourable for its formation. The largest area of tropical peatland is located on the islands of Borneo and Sumatra. It can also be found significantly in other parts of Indonesia, Malaysia, Vietnam, Thailand and Philippines (Table 1) [6].

Recent mapping by Wahyunto et al., 2014 shows that peatlands area in Indonesia varies from 13 to 26.5 million ha. Sumatera has the largest area of peatlands (6.436.530 ha), followed by Borneo (4.778.005 ha) and Papua (3.691.081 ha) (Table 2) [2].

3. Geotechnical properties of peat

The geotechnical properties of peat soil has been done by many researchers, to ensure the construction which built this soil is safe after completion. Review from literatures indicates that peat soil properties varies from one place to another. They have high water content, high liquid limit, low specific gravity, high acidity, and high organic content (Table 3).

4. Construction problems and solution

Peat, by virtue of its heterogeneity, is a problematic soil [10]. The most common problems related to the construction of infrastructures can be categorised as settlement of peat, low bearing capacity of peat, poor stability of peat during excavation and high ground water table. Settlements could occur at various modes, such as tipping, differential and uniform settlements,

| Country            | Area (km²) | Country   | Area (km²) |
|--------------------|------------|-----------|------------|
| Canada             | 1.500.000  | Germany   | 16.000     |
| USSR (the former)  | 1.500.000  | Brazil    | 15.000     |
| United States      | 600.000    | Ireland   | 14.000     |
| Indonesia          | 170.000    | Uganda    | 14.000     |
| Finland            | 100.000    | Poland    | 13.000     |
| Sweden             | 70.000     | Falklands | 12.000     |
| China              | 42.000     | Chile     | 11.000     |
| Norway             | 30.000     | Zambia    | 11.000     |
| Malaysia           | 25.000     | 26 other countries | 220 - 10.000 |

| Province/Island   | Area (ha) |
|-------------------|-----------|
| Riau              | 3.867.414 |
| South Sumatera    | 1.262.384 |
| Jambi             | 621.089   |
| Others            | 685.643   |
| SUMATERA          | 6.436.530 |
| West Borneo       | 1.680.134 |
| Central Borneo    | 2.659.234 |
| Others            | 438.637   |
| BORNEO            | 4.778.005 |
| Papua             | 2.644.438 |
| West Papua        | 1.046.511 |
| PAPUA             | 3.691.081 |

| Lokasi     | Pulau  | Kadar Abu (%) | Kadar Organik (%) | Kadar Air (%) | Liquid Limit (%) | Specific Gravity | pH     | Referensi |
|------------|--------|----------------|-------------------|---------------|------------------|------------------|--------|-----------|
| Pontianak  | Kalimantan | 1,2           | 98,8              | 632           | 260              | 1,42             | 4,8    | [7]       |
| Kota Gambut| Kalimantan | 3,29          | 96,71             | 198           | 182              | 1,47             | 6,47   |           |
| Duri       | Sumatera | 21,96          | 78,04             | 235,4         | 440              | 1,6              | 6,47   |           |
| Desa Tampan| Sumatera | 25,2           | 74,8              | 338           | 236              | 1,55             | 3,61   |           |
| Musi       | Sumatera | 50,7           | 49,3              | 235,4         | 274              | 1,82             | 3,3    |           |
| Kampar     | Sumatera | 53,3           | 46,7              | 198,2         | 126,31           | 1,64             | -      | [8]       |
| Palangkaraya| Kalimantan | 2            | 98                | 670           | -                | 1,37             | 3,5-5,5| [9]       |
depending on the conditions of peat. These settlements, in excessive, affect the durability and smooth riding of roads or highways. To eliminate the settlement of roads, pile foundation with suspended slabs can be used. Due to the low bearing capacity of peat, it is sometime difficult to access the site during the construction stage (Figure 1). Lightweight materials in the forms of mattresses could be laid and floated on the peat as the temporary platform and access for the construction [5].

Deep excavation on peat with high ground water table could lead to instability of soil or slope. The dramatic drawdown of the ground water table as a result of excavation leads to high mobility of the seepage flow and this causes the failure of the slope. To resolve this, a groundwater barrier is required to cutoff or control the flow in order to ensure the stability of the slope. This could be done through various mechanisms, such as gravity mass, diaphragm wall, sheet piles, jet grouting, stone columns and soil mixing piles. These methods are relatively costly compared with the dewatering scheme [5].

Figure 1. Severe settlement due to poor bearing capacity [5]

Mc Manus et al. suggested three optional method that can be adopted based on the depth. In the event where construction must be performed on a peatland which thickness is < 3m, the approach recommended is peat removal and replacement. If the peat thickness is 3-10 m, adopt the preloading, construction with vertical and sand drain, lightweight fills, surface mattress, stone column, etc. If the peat thickness is > 10m, use deep stabilization techniques (pile, dynamic compaction, etc.) [11].

5. Case studies
Case studies presented on this paper are the construction of road infrastructure located in West Borneo province, Indonesia.

Case 1
This is a district road relocation project on 2020. This project located at Bengkayang District, West Borneo Province, Indonesia. The constructed road are 1,974 km new roads and 4,336 km road widening. Early design shows the new road construction use embankment method with 120 cm thickness at the beginning with chemical soil stabilization on the embankment surface and continued with asphalt pavement. Embankment thickness is reduced until STA 1+695 until it does not use any embankment at all.
Because of doubts from the contractor about this design, negotiation were carried out and mutually agreed upon by the contractor and the employer that a soil investigation and new design were needed on the 1,974 km new road construction. Soil investigation indicates that peat soil was 13 meters deep. High water content, high liquid limit, low specific gravity, and high organic content were found similar to the peat soil properties from literature study. Geotechnical properties of this peat soil are summarized in table 4. New design use embankment with 1,5 meter thick and 2 layers of geotextile, continued with asphalt pavement (Figure 2).

Table 4. Geotechnical properties of peat soil from case 1

| No | Sample | Depth m | Gs | $\gamma_d$ t/m$^3$ | $\gamma_m$ t/m$^3$ | Wn % | e | n | Sr % |
|----|--------|--------|----|------------------|------------------|------|---|---|------|
| 1  | HB.1   | 1.50-2.00 | 2.390 | 1.794 | 2.183 | 21.695 | 0.332 | 0.249 | 100 |
| 2  | HB.2   | 2.50-3.00 | 1.214 | 0.140 | 1.096 | 685.396 | 7.700 | 0.885 | 100 |
| 3  | HB.3   | 2.50-3.00 | 1.692 | 0.373 | 1.385 | 271.178 | 3.535 | 0.779 | 100 |
| 4  | HB.4   | 2.50-3.00 | 1.171 | 0.175 | 1.157 | 560.876 | 5.689 | 0.850 | 100 |
| 5  | HB.5   | 2.50-3.00 | 1.042 | 1.042 | 1.079 | 426.012 | 4.080 | 0.803 | 100 |

Table 4. Geotechnical properties of peat soil from case 1 (continued)

| No | Sample | Wl % | Wp % | Ip % | Classification Unified | e0 | Cc | Cv cm$^2$/dt |
|----|--------|------|------|------|------------------------|----|----|--------------|
| 1  | HB.1   | 21.59 | 16.06 | 5.53 | ML                     | 0.921 | 0.278 | 1.173E-03     |
| 2  | HB.2   | 278.26 | 110.23 | 168.03 | OH                     | 11.969 | 4.259 | 5.138E-04     |
| 3  | HB.3   | 294.07 | 113.79 | 180.28 | OH                     | 7.482 | 2.925 | 3.074E-04     |
| 4  | HB.4   | 266.21 | 107.14 | 159.07 | OH                     | 10.209 | 4.374 | 1.758E-04     |
| 5  | HB.5   | 267.87 | 103.18 | 164.69 | OH                     | 6.407 | 2.782 | 3.233E-04     |

Table 4. Geotechnical properties of peat soil from case 1 (continued)

| No | Sample | Qu Kg/cm$^2$ | c Kg/cm$^2$ | $\phi$ ° | MIT Classification |
|----|--------|--------------|-------------|---------|---------------------|
|    |        |              |             |         | Sand/Organic | Silt | Silt | Clay |
| 1  | HB.1   | 0.188 | 0.142 | 15.216 | 53.5 | 43.0 | 3.5 |
| 2  | HB.2   | 0.054 | 0.039 | 3.205 | 67.5 | 12.0 | 20.5 |
| 3  | HB.3   | 0.204 | 0.121 | 6.560 | 78.0 | 19.5 | 2.5 |
| 4  | HB.4   | 0.028 | 0.073 | 3.776 | 79.5 | 17.8 | 2.75 |
| 5  | HB.5   | 0.065 | 0.075 | 7.012 | 82.5 | 14.8 | 2.75 |

Figure 2. New design of road infrastructure on peat soil
Case 2

This is an embankment project for 1,378 km industrial road on 2007 at Sanggau District, West Borneo Province, Indonesia. This road was constructed on 19 meter thick peat soil. Embankment design for preloading was 10 meter of compacted landfill with timber piles of 15 cm diameter and 4.5 meter length, and 16 meter deep vertical drains were installed below the embankment. Geotextile also used below the embankment. This design is shown at figure 3 below.

During the construction stage, sliding and creek were reported on the embankment, resulted in massive settlement (figure 4 and 5). Timber piles and geotextiles installed were found floating on the peat swamp beside the embankment. Despite of this problems, the contractor continued the embankment until reaching the final elevation which agreed on contract. The settlement was reported from 1.9 to 3.9 meter deep. This problems was solved by adding more landfill at the left and right side of the embankment as counter weight. Landfill volume which agreed on contract from 223.903 m$^3$, increased to 529.687 m$^3$.

![Figure 3. Road design](image)

![Figure 4. Sliding](image)

![Figure 5. Creek](image)

6. Conclusion

These case studies show the lack of technical data required for design and design failure. The design from case 1 use embankment with geotextile and on case 2, the massive settlement
problem solved solved by adding more landfill at the left and right side of the embankment as counter weight but resulted in increasing landfill volume more than twice the original volume. Construction on peat soil requires special attention, especially on the design and execution. Unit price contract is preferable over lumpsum contract due to the high uncertainties of peat soil. Environment impact due to construction on peat soil need to be accounted for, also the risk of peat fires need to be considered if dewatering used..

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