Land Suitability Evaluation for Settlement Based on Soil Bearing Capacity in Banda Aceh, Indonesia

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ABSTRACT

On December 26th, 2004, an Ocean earthquake tsunami struck off the western coast of Sumatra, Indonesia. Banda Aceh was the largest settlement area and the most devastated due to the natural disaster. Today, ten years after the disaster, it has become necessary to evaluate the suitability of the settlement area to determine which areas are compatible for settlement purpose. This article examines the concept of land suitability evaluation and its implementation possibility for settlements based on the bearing capacity of the soil. The focus of the study is on the criteria of soil bearing capacity and the GIS method will be adopted for the implementation. To ensure that the application works, a geospatial analysis compiled by the variable soil bearing capacity that can be observed and measured for the terms of settlement is required. The results show that Banda Aceh as a whole falls under the order of ‘S’ (suitable) for settlement based on the soil bearing capacity.

INTRODUCTION

Rebuilding the settlements in disaster-affected areas is highly associated with comfort and a sense of anxiousness developed among the community to the possibility of disasters in the future. In addition, housing facilities fostered by residents often fail to comply to the physical condition of the soil and the environment. According to, Chiara and Koppelman [1] ENREF_7 housing design has several requirements: a) attractive, appropriate and economical building foundation, b) provides safety, comfort and is functional, c) able to balance the nature with the foundation of the structure. Therefore, it is necessary to evaluate the suitability of soil settlement with the current environmental conditions. Soil suitability evaluation is an approach or a way to determine the potential of soil resources [2]. Meanwhile Rossiter [3] sees it as the process to predict the potential use of soil based on their attributes. Soil appropriateness result will provide some information or guideline on the soil use. Niekerk [4] states that soil evaluation is also an integral part of soil use planning to ensure continuous soil management. Soil use for settlement should be harmonious with the soil supporting ability [5]. Therefore, it is essential to measure whether or not the building structure on the soil will affect the soil bearing capacity. Kaiser, Godschalk [6], and S etyaningrum [7] suggest that, from the planning point of view, soil bearing capacity is defined as the nature’s ability to fully support the growth of the people, physical development or human resource exploration without destru ction of the nature. Specifically Singh and Prakash [8] and Muchtar [9] define that soil bearing capacity is the land capacity which supports the physical structural weight and others such as the roof, moving weight, wind weight, and earthquake. Erizal [10] adds that allowable bearing capacity maximum weight of the soil resistivity can support the settlement’s land use. Popescu, Deodatis [11] reveal that the influence of random heterogeneity soil properties on the bearing capacity of the soil needs to be modelled as spatial.

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Methodology:
A direct field testing seeks to determine the soil resistance on the conical with a CPT (cone penetration test) [12]. The work mostly concentrates on the spatial analysis of the CPT values and land suitability evaluation model of FAO [13, 14] adjusted for settlements. The GIS is used in managing spatial data and presenting visual classification results.

RESULTS AND DISCUSSION

(i) Soil Bearing Capacity:
Data showing the capacity of the land mass are needed in every construction phase of a building structure. Soil bearing capacity needs to be evaluated to enable calculating and planning for correct foundation dimensions that can support the building of the structure. If soil cannot carry the structure, intervention should be made to increase the measurement of soil bearing capacity into desired results. The City of Banda Aceh is required to conduct an investigation on soil bearing capacity especially for three storey and above buildings [15]. Considering that Banda Aceh was hit by Tsunami and lies in an earthquake-prone area, settlements should be adjusted to the soil bearing capacity. By using the GIS [16, 17] the distribution of CPT measurement results can be seen in Fig 1.

CPT data were analyzed to obtain the building foundation bearing capacity. A shallow foundation is used for settlement, while the foundation depth reviewed here is up to 1 m width and depth. This measurement overview was based on the consideration of the average depth of home foundation in Banda Aceh. Many formulas can be used to analyze the soil bearing capacity for building foundations. The option used depends highly on available data. Martini [18] states that what must be noted is the results of the calculation of the soil bearing capacity that increase steadily along with the size of the foundation whereby the larger the foundation, the higher the soil bearing capacity. Below is the analysis of a shallow foundation using Meyerhof formula [18-20].

\[
q = \frac{q_c \cdot B \left(1 + \frac{D}{B}\right)^{\frac{1}{1.9}}}{S_f}
\]

\(q\) = soil bearing capacity, \(q_c\) = conus value, \(B\) = width of foundation, \(D\) = depth of foundation, and \(S_f\) = Safety factor

(ii) Spatial Analysis of Soil Bearing Capacity:
The result analysis of the soil bearing capacity using Mayeroff formula still comes in point. To predict the overall land surface, the GIS is used with the interpolation concept. Spatial classification based on the field soil bearing capacity value is used in applying this function [21, 22]. In summary, interpolation is the process of changing the data points into the area. Inverse distance weighted, natural neighbor, spline, and kriging trend are rules used in the interpolation. Furthermore Booth and Mitchell [23]; Gorr and Kurland [24] and Pramono [25] confirm that Kriging rules has the advantages of unibias properties, minimum variance, and it serves as a a linear combination rather than observation. Kriging interpolation results from the data analysis of the soil bearing capacity in Banda Aceh, are presented in Figure 2 as follows:
(iii) Land Evaluation Suitability for Settlement:

Soil consistency can be determined by its soil bearing capacity. The relationship between the consistency and the conus pressure is proportionate, where the higher the conus value on the CPT measurement, the harder the soil [8, 26, 27]. This can be referred to in Table 1.

<table>
<thead>
<tr>
<th>Land consistency</th>
<th>Soil bearing capacity (kg/cm²)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Very soft</td>
<td>0.0 - 0.3</td>
</tr>
<tr>
<td>Soft</td>
<td>0.3 - 0.6</td>
</tr>
<tr>
<td>Medium</td>
<td>0.6 - 1.2</td>
</tr>
<tr>
<td>Hard</td>
<td>1.2 - 2.4</td>
</tr>
<tr>
<td>Very hard</td>
<td>2.4 - 4.8</td>
</tr>
<tr>
<td>Xtra hard</td>
<td>&gt; 4.8</td>
</tr>
</tbody>
</table>

The land suitability evaluation system has adopted the FAO. Suitability catagories have been adopted as well to represent class. Order S corresponds with class S1 (highly suitable), S2 (moderately suitable) and S3 (marginally suitable). Order N does not comply with Class, N1 (currently not suitable) and N2 (permanently not suitable). The ground consistency which became thematic settlement eligibility criteria is in line with the literature review analysis [5, 13, 28, 29]. With this concept of matching, a map of interpolation results (Fig.2) is reclassified based on the class suitability criteria. Results are reclassified into the land suitability map as presented in Fig 3. The distribution maps of soil bearing capacity provides preliminary information on the carrying capacity of land. Further analysis is related to the burden and depth of the foundation plan. It is to determine the technologies that will be applied based on the bearing capacity condition.

**Summary:**

The results of this study indicate that the soil bearing capacity of the land in Banda Aceh as a whole is in the order of S (fit). Based on the suitability class, half of the Banda Aceh area is in a class of S3 (marginally suitable) and the rest is of S1 (highly suitable), S2 (moderately suitable). In detail, the percentage of suitability classes of the S1 area is 1633 ha, or 27%, S2 is 1121 ha or 18%, and S3 for 3383 ha or 55%. This indicates that
the soil bearing capacity in all areas of Banda Aceh can well support basic settlement (maximum of 3 floors). This however, does not apply to higher buildings. Furthermore, this study can be used as a basis of settlement planning. For a broader context, this work can also consider the influence of various environmental variables such as hydrology, climate factors even disasters like floods, earthquakes and tsunami.

REFERENCES