Redesigning the foundation of Bangli solar power plant on a former landfill

A A P Indrayanti[1], I W Wiraga[1], I M Jaya[1], I G A I Mas Pertiwi[1]

[1] Department of Civil Engineering, Politeknik Negeri Bali, Kampus Bukit Jimbaran, Bali, Indonesia

E-mail: ajung_putri@pnb.ac.id

Abstract. Bangli solar power plant has 5004 solar modules and uses concrete foundations to support those modules. Due to the location of this power plant was a former landfill, after 5 years in operation, 121 foundations have dropped to lower level. The soil under foundation is not enough to support modules sufficiently. In this paper, a new design has been proposed to correct this problem. The first step is to test the carrying capacity of soil through Sondir boring. Using Standard Penetration Test (SPT) obtained that the layer of hard soil is located at a depth of -10m from the original soil surface with type of soil layer above the elevation of hard soil in the form of silt soil. Using a palm foundation, carrying capacity of a foundation with a width of less than 1.2 meters and a depth of foundation of 1 meter. This makes the average carrying capacity is only 0.39 - 1.20 kg/ square cm or the value is too small for foundation of solar power plants. The proposed foundation is a 50 x 50 cm palm foundation that is laid on a geotextile bed. The area of the geotextile depends on the area of decreased foundation.

1. Introduction

In landfill redevelopment, there are some main factor that have to be considered such as location, type of waste, dept of waste, degree of contamination government regulation and financials aspect [1]. It also can be the addition of perimeter cut-off wall to prevent a problem in seepage in municipal solid waste (MSW) [2]. Differential settlement under the landfill final cover and floor liner can be estimated using random fields in modelling the waste [3]. Foundation design is part of landfill redevelopment, where the taller structure of pile foundation is not allowed in former landfills [4]. The foundation at the top of soil should be built at 200 mm of thickness to prevent wind and soil erosion [5]. This soil reinforcement has been investigated on [6, 7].

A pile load test is applied for measuring the total head settlement especially when conducting design and maximum test load [8]. A procedure to predict the load settlement and bearing capacity was developed at [9]. Characteristic of bearing capacity of reinforced of sandy ground can be obtain using a quantitative evaluation. These tests are conducted in deep-footing and wide-slab mechanisms [10]. Another test that should be done for soil investigation is a standard penetration test (SPT) for comparing to other methods. This method uses a simple equipment, rugged, and inexpensive but, the test results a representative the sample of the soil [11].

In this paper, foundations of Bangli Solar Power Plant that lays on the former landfill was investigated and then made a redesign for these foundations due to drop problem in same area. The location and problem of the Bangli Solar Power Plant foundation is shown in Figure 1 and 2 respectively.

Figure 1. Bangli solar power plant area.

Figure 2. Foundations dropped in some area of Bangli Solar Power Plant.

2. Methodology

2.1. Land investigation

Land investigations are a very important step in preliminary work of civil engineering projects. Sufficient information about the physical and mechanical properties of the soil at the project site is very helpful in making a safe and economical design and avoiding difficulties during construction. The main purpose of a soil investigation is to determine the type of soil layer and its thickness [1]. Another purpose of soil investigation is to obtain soil samples for identification, classification and laboratory testing to obtain the required soil parameters. The results of the soil investigation must provide sufficient information to be able to determine the type of foundation that is most appropriate for a particular type of structure, or to anticipate problems that may arise during excavation. Soil investigations need to be carried out to a certain depth depending on the type and size of the project. The results of the soil investigation must also be able to provide information that there is no soft soil layer below the planned foundation depth, to avoid decreases that exceed acceptable tolerances. If it is planned to use a pile, the conditions under the end of the pile must be fully known to ensure that the tip of the pile is above the soil layer with the required carrying capacity. The method commonly used to carry out soil testing in the field is by hole testing, drilling (boring), soil sampling [2]. As a continuation of soil testing activities, physical and mechanical testing of the soil, both carried out directly in the field and in the laboratory. The results of this test are expected to support and support the results of field investigations. Some tests can be carried out directly in the field such as, penetration testing, both statistical and dynamic testing, shear tests and direct loading. Laboratory tests are included testing the content weight, specific gravity, air content, Atterberg limits, grading test, shear strength, compressive strength and compressive testing. To get this information, a field test was designed in the form of Sondir testing in the area. Based on the type of field testing, an analysis will be made so that conclusions can be made about the carrying capacity of the soil that can be mobilized by the foundation for both shallow and deep foundations (drill piles/piles). Furthermore, recommendations will be given to the planner or building owner about the type of foundation that is deemed appropriate and appropriate for use in this construction. The planner will calculate the size, depth or number of bored piles in each foundation according to the amount of load received by the foundation. Considering the land area of the area to be analysed, the sondir test is carried out in 5 points. The depth of testing until reaching the manometer reading shows a voltage of 250 kg/cm2. This test location has been approved by the building owner (planner). The number of tests is considered sufficient to represent the area to be developed so that the recommendations given are ideal and represent the entire development area.

2.2. Drilling
Drilling work is almost always required in land investigations. The purpose of this drilling work is to reach a certain depth of soil or to obtain samples of undisturbed soil. To make a drill hole can be done by hand drill or machine drill. Hand drill is done by using a drill bit (auger) mounted on the lower end of the drill stem. At the top of the drill stem mounted handlebars to rotate the drill tool. Hand drills can only be carried out on soft clay soils with firm hardness, with a depth of 8-10 meters. The type of drill bit commonly used is the Iwan drill bit. Other types of drill bits are spiral drill and helical drill. Machine drills are used when needed to drill holes in harder layers of soil, or to speed up drilling work on soft or loose soil. For hard soil, the drill bit that is commonly used is the core barrel.

2.3. Standards penetration test
SPT is a dynamic penetrometer where this test is done by drilling the ground. After the desired depth is reached, the split spoon sampler is inserted into the bottom of the hole and then poked using a hammer weighing 63.5 kg which is dropped from a height of 75 cm. After being stabbed as deep as 15 cm, then the number of strokes needed to stab as deep as 30 cm is recorded. The number of hits is called the N value or standard penetration resistance value. Like the Sondir, the N value on the SPT does not automatically indicate the carrying capacity of the land concerned. The relationship between the value of N with the value of the deep friction angle and the value of q_u is shown in Tables 1 and 2 [1].

Table 1. Relation of N and D_r and inner sliding angle.

N	Relative density $D_r = \frac{e_{max} - e}{e_{max} - e_{min}}$		Inner sliding angle According to Peck	Inner sliding angle According to Meyerhof
0 – 4	Very loose	0.0 – 0.2	< 28.5	< 30
4 – 10	Loose	0.2 – 0.4	28.5 – 30.0	30 – 35
10 – 30	Moderate	0.4 – 0.6	30 – 36	35 – 40
30 – 50	Solid	0.6 – 0.8	36 – 41	40 – 45
> 50	Very Solid	0.8 – 1.0	> 41	> 45

Table 2. Relation between N and q_u.

Consistency	very soft	soft	moderate	hard	very hard	solid
N	< 2	2 – 4	4 – 8	8 – 15	15 – 30	> 30
q_u (kg/cm^2)	< 2.5	0.25 – 0.50	0.5 – 1.0	1.0 – 2.0	2.0 – 4.0	> 4.0

Table 3. Relation between N and *qu*.

N	Consistency	Free compressive strength (q_u) (kN/m^2)
<2	Very soft	<25
2-4	Soft	25-50
4-8	Moderate	50-100
8-15	Stiff	100-200
15-30	Very Stiff	200-400
>30	hard	>400

2.4. Sondir test

The sondir tool is a static penetrometer that is widely used in Indonesia. This tool comes from the Netherlands and is known as the Dutch-Cone Penetrometer Test. The working principle of this tool is to press the tip of the penetrometer (conus) down with a pressure machine that is anchored to the ground, then record the value of the conical penetration resistance and ground sticking resistance. Resistance to conical penetration is the resistance of the soil to the conical tip expressed in force per unit area. Sticky resistance is the shear resistance of the soil to the biconvex sheath in units of force per unit length. There are two types of penetrometer tips commonly used, namely conus (standard type) and biconus (friction sleeve or adhesion jacket type). This cone is a cone with an angle of 60% with a cross-sectional area of 10 cm^2, which is installed in a series of deep rods and sondir pipes. In the standard type, the measurement results are cone penetration resistance (cone values). This is obtained by pressing only on the stem only. The force required to press the cone tip is measured by a pressure gauge mounted on a pressure machine. Measurements are made at certain specified depths and are usually done for every 20 cm depth. After measuring at a depth, the sondir pipe is pressed to the next depth, then the next measurement is done by pressing the inside rod, and the force required is measured by reading a pressure gauge.

In the Biconus type, the measurement results obtained are cone values and sticky barriers, which are carried out by pressing the inner stem. Initially, deep stem pressure only causes the cone tip to enter, so that only the cone value is measured. After the conus is pressed as deep as 4 cm, then the subsequent pressure will cause the conus to compress and the friction sleeve together, 4 cm deep. So, the value read on a pressure gauge is the sum of the cone value and the sticking resistance. The value of sticky resistance is obtained by subtracting the value of cone from the number of cone values and sticking value. To get the next reading, the Sondir pipe is pressed, so that the cone, inner stem and viscous veil will be pressed simultaneously. Then the inner stem is pressed, and the process repeats as described above. There are two types of pressure machines, namely the light type and the heavy type. The light type can measure pressures up to 150 kg/cm^2, while the heavy type can measure up to 400 kg/cm^2. The penetration depth can reach 30 m if the soil layer is a soft soil layer. The value of cone penetration resistance obtained from the results of the Sondir test does not directly indicate the carrying capacity of the land concerned. The conus value is an empirical number, which must be analysed first to be used as a basis for calculating the carrying capacity of the soil.

2.5. Calculation of carrying capacity based on SPT value

Calculation of carrying capacity for shallow foundations (soles) based on N values can use the formula from Meyerhof, where the carrying capacity of the soil is influenced by the value of N and width of the foundation (B).

- For palm foundations with a width of $B \leq 1.2$ m, the bearing capacity formula is:

$$q_a = 12N \text{ (kN/m}^2\text{)} \tag{1}$$

- For palm foundations with a width of $B > 1.2$ m, the formula used is:

$$q_a = 8N\left(\frac{B+0{,}3}{B}\right)^2 \text{ (kN/m}^2\text{)} \tag{2}$$

According to Bowels (1968) the carrying capacity value proposed by Meyerhof is still considered to be too conservative, so the Meyerhof Formula is revised by adding the foundation depth function from the ground surface:

- For foundation width $B \leq 1.2$ meters, the bearing capacity formula is:

$$qa = 20.N.Kd \tag{3}$$

- For palm foundation with a width of $B > 1.2$ meters the carrying capacity of the soil is:

$$q_a = 12{,}5N\left(\frac{B+0{,}3}{B}\right)^2.Kd \tag{4}$$

where:

q_a = Net carrying capacity for a maximum reduction of 1" (kN / m^2)

$$Kd = \left(1 + \frac{0{,}33D}{B}\right) \tag{5}$$

B = foundation width (m)
D = foundation depth (m)

The carrying capacity is then compared to the magnitude of the voltage distributed by the base ground foundation (building load divided by the area of the foundation). Net soil carrying capacity (q_a) > stress due to the building above it. Calculation of bored pile foundation based on SPT value can be used Meyerhof formula:

$$Q_u = 4N_b.A_b + \frac{\overline{N}.A_s}{50} \tag{6}$$

Q_u = ultimate pole capacity (ton)
A_b = Area of base of pole (ft^2)

N_b = N average around the base of the pole (at 8d above to 4d below the base of the pole)
N = N average along the pole
A_s = area of the pole blanket (ft^2)
d = pole diameter (ft)

2.6. Calculation of carrying capacity with Sondir data

The carrying capacity of the soil for square and longitudinal foundations is calculated using the Meyerhof formula. Carrying capacity is adjusted to the width of the foundation.

- For foundation widths ≤ 1.2 m: $q_u = \frac{q_c}{30}(kg/cm^2)$ (7)
- For foundation width> 1.2 m: $q_u = \frac{q_c}{50}\left(\frac{B+0,30}{B}\right)^2 (kg/cm^2)$ (8)

While the bearing capacity of the pile foundation using the sondir data the formula is used:

$$Q_{sp} = \frac{q_c.A_b}{F_b} + \frac{C.U}{F_s} \quad (9)$$

where:

Q_{sp} : Axial carrying capacity of bore pile permit
B : Foundation width
Q_c : The cone resistance at the end of the pole, is the average value at 4D depth above and below the end of the pole
A_b : Crossing area of the Mast Post
C : Total clef resistance along the pile
U : Around the pole
F_b : Safety Factor (taken = 3)
F_s : Safety Factor (taken = 5)

3. Results of land investigations

The results of field investigations using the Sondir, boring and SPT methods are presented in tables and graphs with the following explanation:

- The drill log table that is shown as Table 4 can be plot as graphs as shown in Figure 3. These results presented the type of soil layer at a certain elevation. The drill log also presents graphs of SPT test results on the respective bore holes.
- The results of the sondir test are cone values at each additional depth of 0.2 m and the average cone value at a certain depth.
- 0.00 elevation is calculated from the local elevation at the test point.
- Sondir data shown in tables and graphs refer to the elevation of the local test point.
- The sondir test is carried out until a conus reading a value of 250 kg /cm^2. In addition to the cone value, this test can also determine the value of soil friction or attachment.

Table 4. Sondir test results for bearing capacity analysis.

H (m)	Conus Cw (kg/cm^2)	Average of Conus qc (kg/cm^2)	Total of Resistance Tw (kg/cm^2)	Friction Resistance Kw (kg/cm^2)	Local Resistance Lcf (kg/cm^2)	Adhesive Resistance Lcf x 20 (kg/cm^1)	Total of Resistance (Cumulative) Tf (kg/cm^1)
1	2	3	4	5 = 4 - 2	6 = 5 : 10	7 = 6 x 20	8
0.00	0		0				0
0.20	10	11.00	12	2.0	0.2	2.0	2.0
0.40	20	11.71	22	2.0	0.2	2.0	4.0
0.60	10.0	13.14	12.00	2.0	0.2	2.0	6.0
0.80	11.0	13.14	15.00	4.0	0.4	4.0	10.0
1.00	15.0	11.71	20.00	5.0	0.5	5.0	15.0
1.20	16.0	11.71	17.00	1.0	0.1	1.0	16.0
1.40	10.0	13.00	15.00	5.0	0.5	5.0	21.0
1.60	10.0	13.43	15.00	5.0	0.5	5.0	26.0
1.80	10.0	13.71	15.00	5.0	0.5	5.0	31.0
2.00	10.0	15.14	16.00	6.0	0.6	6.0	37.0
2.20	20.0	16.00	25.00	5.0	0.5	5.0	42.0
2.40	18.0	17.14	24.00	6.0	0.6	6.0	48.0
2.60	18.0	17.43	23.00	5.0	0.5	5.0	53.0
2.80	20.0	16.29	26.00	6.0	0.6	6.0	59.0
3.00	16.0	15.43	21.00	5.0	0.5	5.0	64.0
3.20	18.0	22.86	22.00	4.0	0.4	4.0	68.0
3.40	12.0	27.86	15.00	3.0	0.3	3.0	71.0
3.60	12.0	32.00	15.00	3.0	0.3	3.0	74.0
3.80	12.0	34.43	14.00	2.0	0.2	2.0	76.0
4.00	70.0	37.71	82.00	12.0	1.2	12.0	88.0
4.20	55.0	40.29	70.00	15.0	1.5	15.0	103.0
4.40	45.0	47.29	50.00	5.0	0.5	5.0	108.0
4.60	35.0	46.57	40.00	5.0	0.5	5.0	113.0
4.80	35.0	45.86	42.00	7.0	0.7	7.0	120.0
5.00	30.0	47.29	36.00	6.0	0.6	6.0	126.0
5.20	61.0	52.29	75.00	14.0	1.4	14.0	140.0
5.40	65.0	57.29	75.00	10.0	1.0	10.0	150.0
5.60	50.0	65.86	62.00	12.0	1.2	12.0	162.0
5.80	55.0	63.57	65.00	10.0	1.0	10.0	172.0
6.00	70.0	59.43	82.00	12.0	1.2	12.0	184.0
6.20	70.0	56.29	82.00	12.0	1.2	12.0	196.0
6.40	90.0	52.43	105.00	15.0	1.5	15.0	211.0
6.60	45.0	46.29	55.00	10.0	1.0	10.0	221.0
6.80	36.0	39.86	45.00	9.0	0.9	9.0	230.0
7.00	28.0	30.71	34.00	6.0	0.6	6.0	236.0
7.20	28.0	31.43	33.00	5.0	0.5	5.0	241.0
7.40	27.0	32.71	32.00	5.0	0.5	5.0	246.0
7.60	25.0	35.86	30.00	5.0	0.5	5.0	251.0
7.80	26.0	39.29	31.00	5.0	0.5	5.0	256.0
8.00	50.0	45.29	60.00	10.0	1.0	10.0	266.0
8.20	45.0	51.57	56.00	11.0	1.1	11.0	277.0
8.40	50.0	56.43	61.00	11.0	1.1	11.0	288.0
8.60	52.0	54.14	65.00	13.0	1.3	13.0	301.0
8.80	69.0	53.43	73.00	4.0	0.4	4.0	305.0
9.00	69.0	74.86	75.00	6.0	0.6	6.0	311.0
9.20	60.0	103.14	70.00	10.0	1.0	10.0	321.0
9.40	34.0	129.00	40.00	6.0	0.6	6.0	327.0
9.60	40.0	154.86	52.00	12.0	1.2	12.0	339.0
9.80	200.0	170.67	200.00	0.0	0.0	0.0	339.0
10.00	250.0	198.00	250.00	0.0	0.0	0.0	339.0
10.20	250.0						
10.40	250.0						

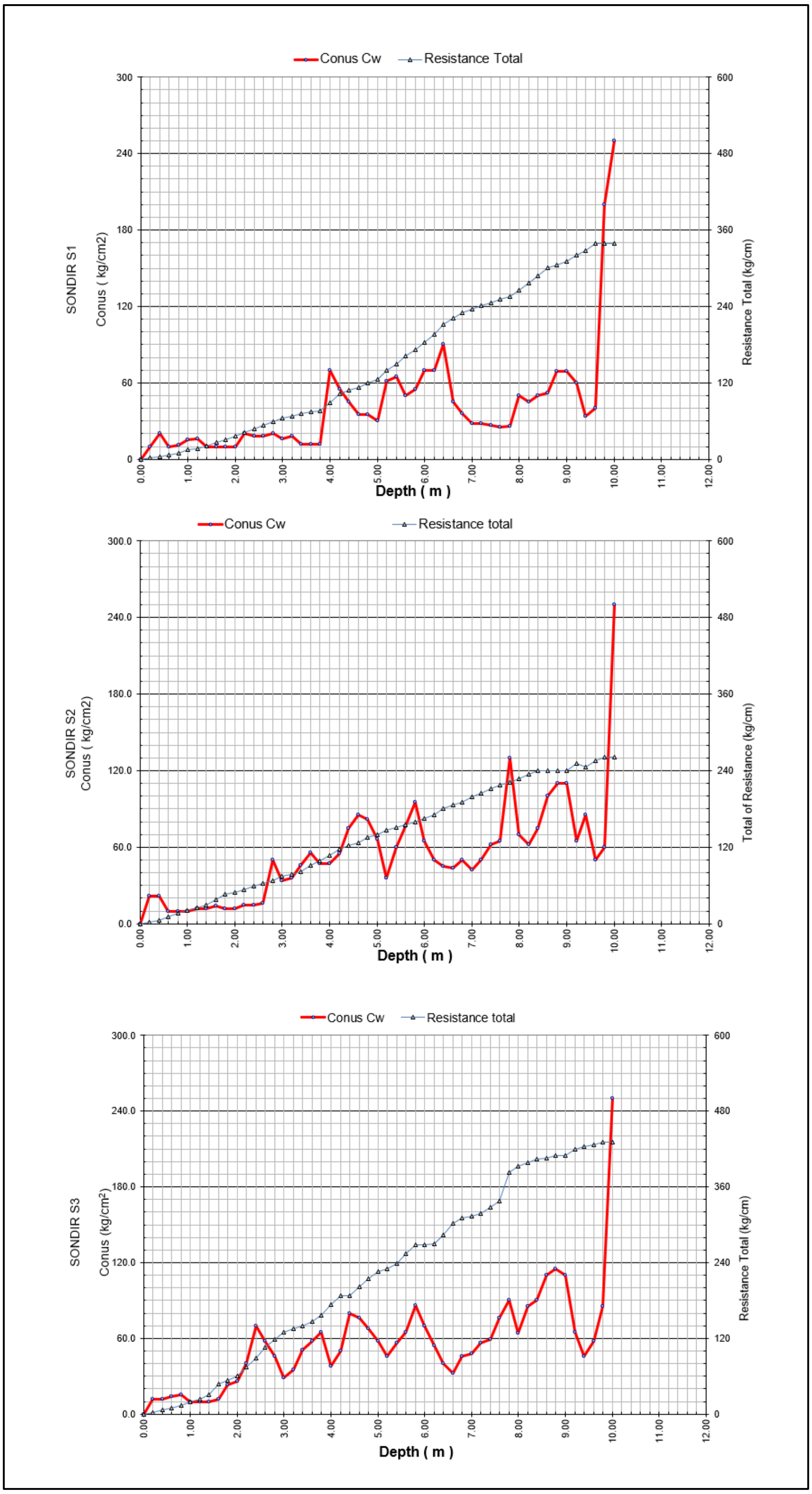

Figure 3. Sondir test results at different location.

Table 5. The depth of hard soil when this test is carried out.

Location	Dept (m)	Type of Soil
S1	-10	rock
S2	-10	rock
S3	-10	rock
S4	-10	rock
S5	-10	rock

Table 6. Carrying capacity of the palm foundation at a depth of - 1 meter from the surface of the ground.

Location	Width of foundation (m)	Depth (m)	Carrying capacity (kg/cm^2)
S1	≤ 1.2	1.0	0.39
S2	≤ 1.2	1.0	0.38
S3	≤ 1.2	1.0	0.45
S4	≤ 1.2	1.0	0.96
S5	≤ 1.2	1.0	1.20

Table 7. Carrying capacity of bore pile foundation with tip depth reaching 10 meters from original land surface.

Location	Diameter of bore pile (cm)	Depth (m)	Carrying capacity (ton)
S1	≤ 1.2	-10	53.04
S2	≤ 1.2	-10	45.45
S3	≤ 1.2	-10	50.21
S4	≤ 1.2	-10	59.90
S5	≤ 1.2	-10	65.83

4. Analysis

Five sondir tests have been conducted in the field as shown in Figure 4, all of them showed the depth of hard soil with a manometer reading reaching 250 kg/cm2 at a depth of -10 meters from the original ground surface. In this test, a specific of types of hard soil could be identified, but only known as rock as shown in Table 5. The process should be followed by a drilling test. From the manometer reading, the type of soil layer above the elevation of hard soil is estimated to be silt soil. If the project plan is designed a palm foundation, carrying capacity of a foundation with a width of ≤ 1.2 meters and a depth of foundation of 1 meter, the average carrying capacity is only 0.39 - 1.20 kg/cm2 as shown in Table 6. For 10 meters of depth, the carrying capacity of palm foundations of various location can be seen in Table 7. This value is too small for the foundation of solar power plants due to the soil layer at several test points is a former landfill. Therefore, with the passage of time, a process of decomposition and compression of the subsoil will occur under the solar power plant panel. That is what causes the occurrence of a decrease in several segments of the solar panel at this time. Given the small carrying capacity of the soil in some places, especially at the points of the former landfill, it should be done innovation and engineering under a panel that has decreased. The proposed foundation is a palm foundation laid on a geotextile bed. The size of the foundation is about 50x50 cm. Geotextile stretches should extend to areas that have decreased. Mounting model of the foundation of Bangli solar power plant can be seen in Figure 5. The extent of the geotextile depends on the area of the area that has decreased.

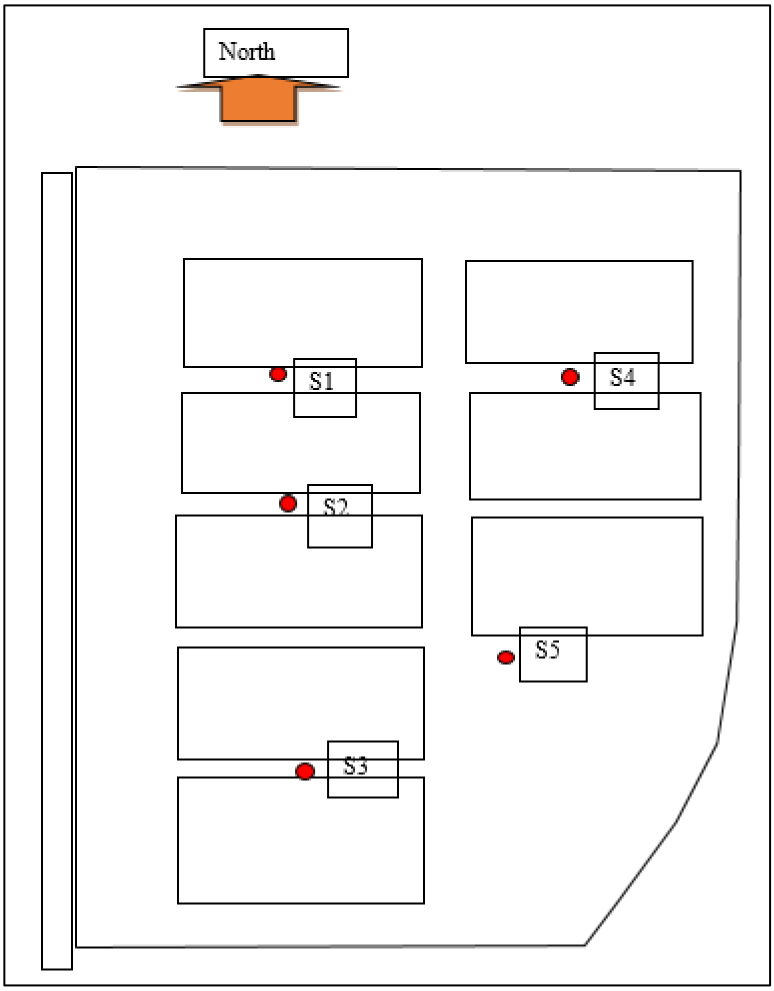

Figure 4. Testing area.

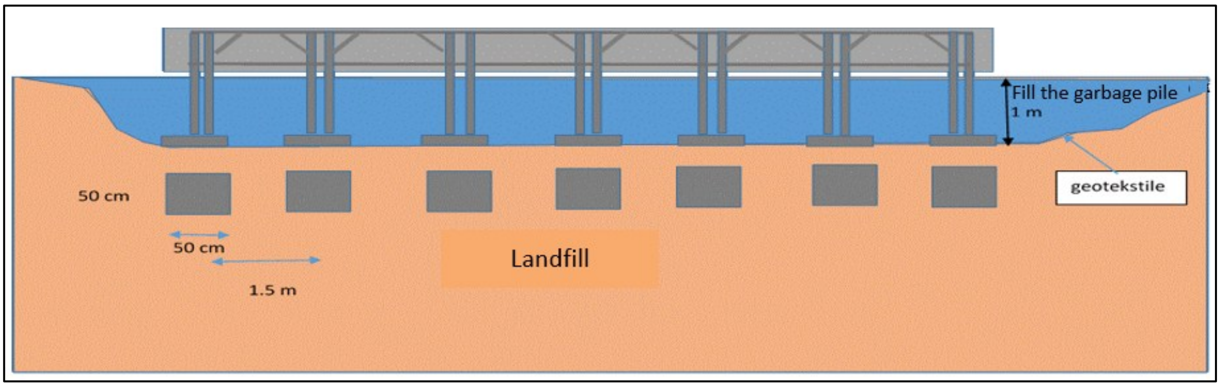

Figure 5. Proposed foundations.

5. Conclusions

In order to fix the problem in dropped foundations, this research proposed the palm foundation that has the size 50 x 50 cm2 and also adding a geotextile bed laid in that area. This strategy is better than the palm foundation with a width of less than 1.2 meters and a depth of foundation of 1 meter with the average carrying capacity is only 0.39 - 1.20 kg/cm2 where this value is too small for the foundation of solar power plants.

6. References

[1] Wiley III J B and Asadi 2002 *Redevelopment potential of landfills. A case study of six New Jersey projects* (UK: WIT Press)
[2] Zhang Q F, Wang Y and Xu Y 2006 *Journal of Hydrodynamics* **18** 613-19
[3] K. C. Foye and T. -Y. Soong 2010 *GeoFlorida: Advances in Analysis, Modeling, and Design* (United States: ASCE) pp 2042 – 51
[4] Bouazza A and Kavazanjian E 2001 *Semantic Scholar*
[5] Manyuchi M M, Mbohwa C and Muzenda E 2017 *6th International Conference on Sustainability, Technology and Education* 66-72
[6] Chen Q 1997 *An experimental study on characteristics and behavior of reinforced soil foundation* (USA: Louisiana State University)
[7] Schlosser F, Jacobsen H M and Juran I 1983 *Proc. of VIII SMFE* 1159-1180
[8] Absolon L T 2015 *Piling European Practice and Worlwide*
[9] J Binquet and K L Lee 1975 *Journal of the Geotechnical Engineering Division* **101** 1257-76
[10] Huang C C and Menq F Y 1997 *Journal of Geotechnical and Geo environmental Engineering ASCE* **123** 30–36
[11] El-Reedy M A 2017 *Soil Investigation and Pile Design Onshore Structural Design Calculations* (Amsterdam: Elsevier) pp 345–385.