LOGIC
Journal of Engineering Design and Technology
Vol. 19 No.3 November 2019; p. 145 - 154

p-ISSN : 1412-114X
e-ISSN : 2580-5649
http://ojs.pnb.ac.id/index.php/LOGIC

BEARING CAPACITY ANALYSIS OF BRIDGE FOUNDATION BASED ON CONE PENETRATION TEST DATA AND SOIL PARAMETERS DATA

A CASE STUDY: AIFA BRIDGE IN FAFURWAR DISTRICT, BINTUNI BAY REGENCY WEST PAPUA PROVINCE

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Abstract. The aim of this research to test characteristics of the soil and calculate bearing capacity of the foundation based cone penetration testing data and soil parameters at the Aifa bridge construction field in Fafurwar District, Teluk Bintuni Regency, West Papua Province. Research carried out with survey the construction site of the bridge and conduct a sondir test in accordance with the location of the bridge abutment according to the bridge design drawings. Along with the implementation of sondir test, soil sampling is carried out to be taken to the laboratory for soil characteristics testing. Soil parameter testing carried out in the laboratory, among others, water content test, specific gravity test, unit weight test, Atterberg limit test, soil grain size test, compaction test and shear strength test. From the results of testing the soil characteristics in the laboratory, the type of soil at point 1 is the type of good to bad graded sand soil (SW-SP) with a water content of 17.72%, specific gravity 2.98, liquid limit (LL) = 16,746% included in the non-plastic category. While the location of point 2 is obtained from good to bad graded sand soil type (SW-SP) with a water content of 28.52%, specific gravity 2.73, liquid limit (LL) = 16.746% including the non-plastic category. To analysis of the calculation of the bearing capacity of the foundation Aifa bridge using data from the sondir test results for point 1 was obtained allowable bearing capacity (Q_{all}) is 4.610,44 kN and for point 2 was obtained allowable bearing capacity (Q_{all}) is 3.598,43 kN. For calculating bearing capacity of the foundation using soil parameter data for point 1 was obtained bearing capacity allowable (Q_{all}) is 2.209,93 kN and for point 2 was obtained allowable bearing capacity (Q_{all}) is 655,41 kN

Keywords : Bearing Capacity, Caisson Foundation, Cone Penetration Testing, Soil Parameter

1. INTRODUCTION

The bridge is one of the important infrastructures in people's lives, because aside from being a link to facilitate transportation between two or more regions separated by rivers and valleys [9]. With a bridge, it can indirectly increase the economic growth of a region.

Bridges have 2 (two) parts, namely the superstructure and the substructure [1], [2]. The upper building is a construction that is directly related to the traffic loads that work [2]. Whereas the lower building is a construction that receives loads from the upper building and passes it on to the supporting hard soil layer below. Bridges that are built must have a high level of security and comfort for the wearer so that they can avoid unwanted events [2].

To build a safe bridge including the bridge must have a strong foundation. The bridge foundation comprises several types, one of which is the caisson foundation that will be used for bridge planning in Fafurwar District, Teluk Bintuni Regency, West Papua Province.

A common problem that is often encountered in bridge construction is the occurrence of structural failures, especially in the lower part of the bridge such as the existence of cracks or damage to the bridge abutment that results in overloading experienced by the foundation, a large decrease in the bridge foundation which over time can result structural failure [3].

To minimize the occurrence of structural failures in bridge construction, especially in the lower part of the building, so when the bridge planning work is needed data of soil parameters around the bridge construction site [6], [7]. To get adequate soil parameters, it is necessary to conduct soil tests in the field such as SPT (Standard Penetration Test) and CPT (Cone Penetration Test) [10] and tests conducted in laboratories such as testing specific gravity, soil volume weight, Atterberg limit, analysis of soil grain size, and shear strength soil [5], [11].

After the results of testing the soil characteristics are carried out, one of the main tasks that the planners need to do is calculate or analyze the bearing capacity of the foundation used in bridge planning. To calculate or analyze the bearing capacity of the foundation especially the caisson foundation, we can do it using empirical methods by using soil parameters data that have got and using data from the CPT (Cone Penetration Test).

2. METHODS

In general, the sequence of work steps taken in this study is as shown in Figure 1.

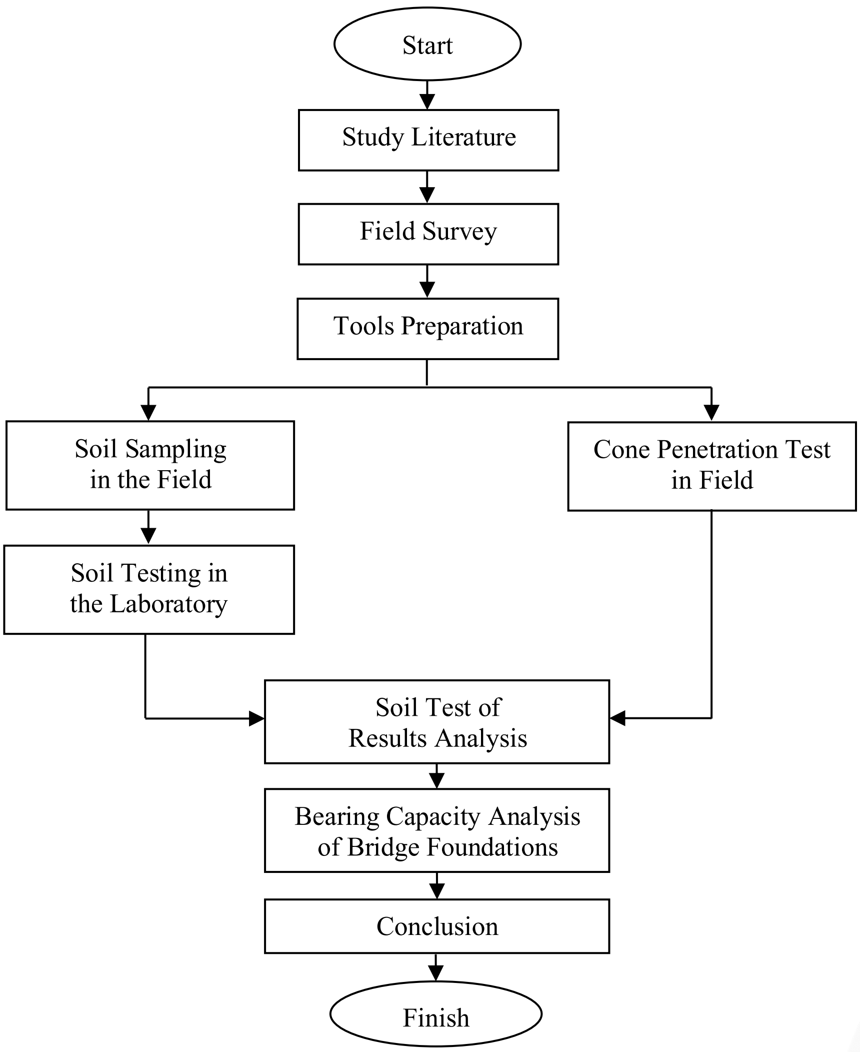

Figure 1. Flowchart of The Research Method

Based on the research flow diagram, the task of the compiler and members of the research is to survey the construction site of the bridge and conduct a sondir test in accordance with the location of the bridge abutment according to the bridge design drawings. Along with the implementation of sondir test, soil sampling is carried out to be taken to the laboratory for soil characteristics testing. Soil parameter testing carried out in the laboratory, among others, water content test, specific gravity test, unit weight test, Atterberg limit test, soil grain size test, compaction test and shear strength test. After the soil parameter data is known from the test results, an analysis of the carrying capacity of bridge foundations uses the type of well foundation (caisson) for construction. Calculation of the carrying capacity of the pitting foundation is divided into 2 (two) types, namely the calculation of the end resistance of the foundation (end bearing, Q_p) and the friction resistance (friction, Q_s). From the calculation of the Q_p and Q_s values, we can determine the ultimate bearing capacity (Q_{ult}) and allowable bearing capacity of the foundation (Q_{all}).

3. RESULTS AND DISCUSSION

3.1 Detail Engineering Design Aifa Bridge

Detail Engineering Design Aifa obtained from the agency Ministry of Public Works of the Directorate General of Highways (BPJN XVII Manokwari). For layout drawing, long section and cross section of the Aifa bridge in Fafurwar District, Bintuni Bay Regency can be seen in Figure 2 annd Figure 3.

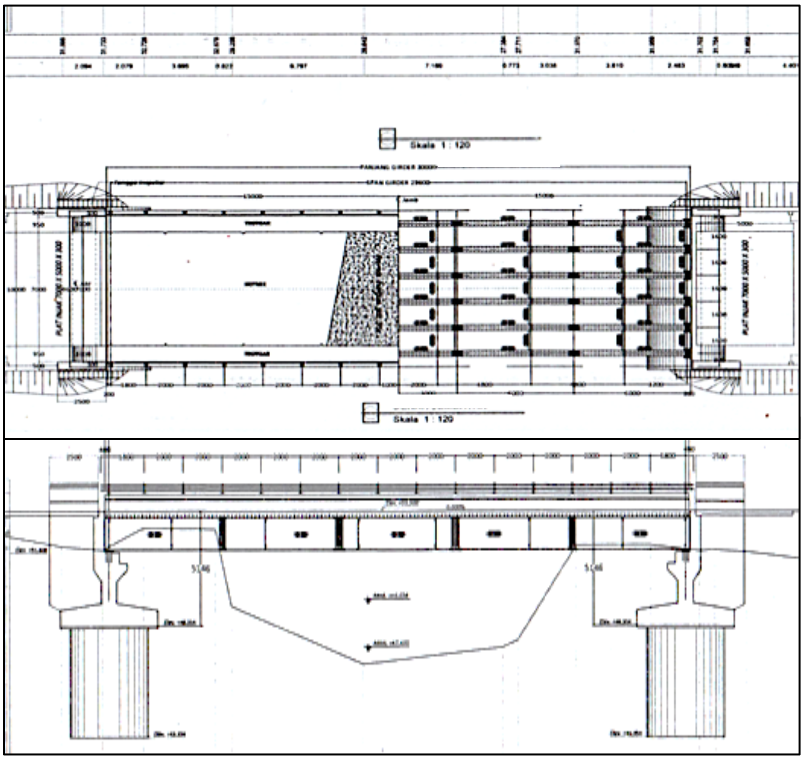

Figure 2. Layout and Long Section of Aifa Bridge

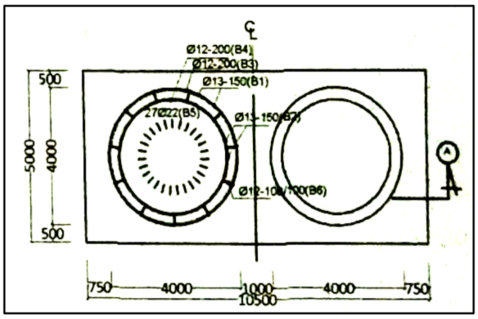

Figure 3. Cross Section of Bridge Foundation

3.2 Results of Soil Investigation

a) Soil Investigation at Point 1

From the results of soil testing conducted in the Soil Testing Laboratory, Department of Civil Engineering, Polytechnic State of Fakfak at the Aifa bridge construction site at Point 1 can be seen in the Table 1. While for the Cone Penetration Test (CPT) conducted, the test results are obtained in Table 2.

Tabel 1. Recapitulation of the Results of Soil Characteristics Test Point 1

No.	Type of Testing	Unit	Test Result
1.	Water content (*w*)	%	17,72
2.	Spesific gravity (G*s*)	-	2,98
3.	Volume of weight (γ)	gr/cm^3	1,096
4.	Atterberg limiy		
	Liquid limit (*LL*)	%	16,75
	Plastic limit (*PL*)	%	NP
	Plasticity index (*PI*)	%	NP
5.	Soil grain analysis		
	Coarse grained soil	%	55,492
	Fine grained soil	%	44,508
6.	Soil classification		
	AASHTO method		A-3
	Unified method		SW-SP
7.	Compaction		
	Optimum water content (W_{opt})	%	33,79
	Volume weight dry (γ_{dry})	gr/cm^3	1,10
8.	Direct shear		
	Cohesion (*c*)	kPa	7,13
	Internal friction angle (ϕ)	^{0}	19,60

Tabel 2. Cone Penetration Test (CPT) Results at Point 1

Depth	Cone Resistance (q_c)	Cone Resistance Total	Swipe Resistance	Sticking Barriers	Value f_s Every 20 cm	Sticking Barriers Total (JHP)	Local Barriers
	q_c	$q_c + f$	f	f_s	F_d	T_f	$F_r = f_s / q_c$
(m)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm)	(kg/cm)	(%)
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
0.0	0	0	0	0.0	0	0	0.00
0.2	5	6	1	0.1	2	2	2.00
0.4	10	12	2	0.2	4	6	2.00
0.6	12	15	3	0.3	6	12	2.50
0.8	20	25	5	0.5	10	22	2.50
1.0	18	23	5	0.5	10	32	2.78
1.2	30	39	9	0.9	18	50	3.00
1.4	20	26	6	0.6	12	62	3.00
1.6	80	105	25	2.5	50	112	3.13
1.8	70	92	22	2.2	44	156	3.14
2.0	140	185	45	4.5	90	246	3.21
2.2	200	265	65	6.5	130	376	3.25
2.4	225	300	75	7.5	150	526	3.33
2.6	120	160	40	4.0	80	606	3.33
2.8	43	58	15	1.5	30	636	3.49
3.0	49	67	18	1.8	36	672	3.67
3.2	45	62	17	1.7	34	706	3.78
3.4	40	56	16	1.6	32	738	4.00
3.6	55	78	23	2.3	46	784	4.18
3.8	86	123	37	3.7	74	858	4.30
4.0	100	145	45	4.5	90	948	4.50
4.2	145	215	70	7.0	140	1088	4.83
4.4	300	410	110	11.0	220	1308	3.67

b) Soil Investigation at Point 2

From the results of soil testing conducted in the Soil Testing Laboratory, Department of Civil Engineering, Polytechnic State of Fakfak at the Aifa bridge construction site at Point 2 can be seen in the Table 3. While for the Cone Penetration Test (CPT) conducted, the test results are obtained in Table 4.

Tabel 3. Recapitulation of the Results of Soil Characteristics Test Point 2

No.	Type of Testing	Unit	Test Result
1.	Water content (*w*)	%	17,72
2.	Spesific gravity (G*s*)	-	2,73
3.	Volume of weight (γ)	gr/cm^3	1,026
4.	Atterberg limiy		
	Liquid limit (*LL*)	%	15,485
	Plastic limit (*PL*)	%	NP
	Plasticity index (*PI*)	%	NP
5.	Soil grain analysis		
	Coarse grained soil	%	56,282
	Fine grained soil	%	43,728
6.	Soil classification		
	AASHTO method		A-3
	Unified method		SW-SP
7.	Compaction		
	Optimum water content (W_{opt})	%	33,79
	Volume weight dry (γ_{dry})	gr/cm^3	1,10
8.	Direct shear		
	Cohesion (*c*)	kPa	7,13
	Internal friction angle (ϕ)	^{0}	19,60

Tabel 4. Cone Penetration Test (CPT) Results at Point 2

Depth	Cone Resistance (q_c)	Cone Resistance Total	Swipe Resistance	Sticking Barriers	Value f_s Every 20 cm	Sticking Barriers Total (JHP)	Local Barriers
	q_c	$q_c + f$	f	f_s	F_d	T_f	$F_r = f_s / q_c$
(m)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm^2)	(kg/cm)	(kg/cm)	(%)
(1)	**(2)**	**(3)**	**(4)**	**(5)**	**(6)**	**(7)**	**(8)**
0.0	0	0	0	0.0	0	0	0.00
0.2	5	6	1	0.1	2	2	2.00
0.4	10	12	2	0.2	4	6	2.00
0.6	10	12	2	0.2	4	10	2.00
0.8	15	19	4	0.4	8	18	2.67
1.0	20	26	6	0.6	12	30	3.00
1.2	28	37	9	0.9	18	48	3.21
1.4	25	33	8	0.8	16	64	3.20
1.6	50	67	17	1.7	34	98	3.40
1.8	70	96	26	2.6	52	150	3.71
2.0	100	138	38	3.8	76	226	3.80
2.2	120	167	47	4.7	94	320	3.92
2.4	150	210	60	6.0	120	440	4.00
2.6	90	127	37	3.7	74	514	4.11
2.8	40	57	17	1.7	34	548	4.25
3.0	48	70	22	2.2	44	592	4.58
3.2	48	71	23	2.3	46	638	4.79
3.4	50	74	24	2.4	48	686	4.80
3.6	57	85	28	2.8	56	742	4.91
3.8	65	100	35	3.5	70	812	5.38
4.0	80	125	45	4.5	90	902	5.63
4.2	120	189	69	6.9	138	1040	5.75
4.4	135	220	85	8.5	170	1210	6.30
4.6	145	240	95	9.5	190	1400	6.55
4.8	340	420	80	8.0	160	1560	2.35

3.3 Bearing Capacity of The Foundation Using CPT Data

a) Bridge foundation at point 1

The foundation data at point 1 was obtained from Figure 3 cross-sectional of the Aifa bridge foundation with the following data:

- Foundation diameter (D_f) = 400 cm = 4,0 m
- Foundation depth (B) = 400 cm = 4,0 m
- Foundation material = reinforced concrete

Calculation of the bearing capacity of the caison foundation using field test data in Cone Penetration Test results is carried out with the following stages:

1) Calculate N_{SPT} value = q_c / 4 of conversions for each soil layer. For details on determining value N_{SPT} can be seen Table 5.

Tabel 5. Relationship Between the Value of q_c and N correction value

Depth (m)	Cone Resistance (q_c) (kg/cm^2)	N_{SPT} Correction Value	Type of Soil
(1)	(2)	(3)	(4)
0.0	0	0,00	Silt Sand
0.2	5	1,25	Silt Sand
0.4	10	2,50	Silt Sand
0.6	12	3,00	Silt Sand
0.8	20	5,00	Silt Sand
1.0	18	4,50	Silt Sand
1.2	30	7,50	Silt Sand
1.4	20	5,00	Sand
1.6	80	20,00	Sand
1.8	70	17,50	Sand
2.0	140	35,00	Sand
2.2	200	50,00	Sand
2.4	225	56,25	Sand
2.6	120	30,00	Sand
2.8	43	10,75	Sand
3.0	49	12,25	Sand
3.2	45	11,25	Sand
3.4	40	10,00	Sand
3.6	55	13,75	Sand
3.8	86	21,50	Sand
4.0	100	25,00	Sand
		$\sum = 342$	

2) Calculate end bearing capacity foundation (Q_p)

A_p = ¼ x π x (D^2) (1)
= 0,25 x 3,14 x (4^2)
= 12,56 m^2

Q_p = 40 x N_p x A_p (2)
= 40 x 25,00 x 12,56
= 12.560,00 kN

3) Calculate friction skin foundation (Q_s)

A_s = π x D x t (3)
= 3,14 x 4,0 x 4,0
= 50,24 m^2

$N_{average}$ = $\sum N_{SPT}$ / n (4)
= 342 / 20
= 17,10

Q_s = 0,1 x N x A_s (5)
= 0,1 x 17,10 x 50,24
= 85,91 kN

4) Calculate self weight of foundation (W_p)

W_p = [(¼.π.($D_{outside}^2$-D_{inside}^2) x D_f x bj. concrete] + [(1/4.π.D_{inside}^2) x Df x bj. cyclop] (6)
= [(¼ x 3,14 x (4^2-$3{,}70^2$) x 4,00 x 24,00] + [¼ x 3,14 x ($3{,}70^2$) x 4 x 22,00]
= (174,082) + (945,705)
= 1.119,787 kN

5) Calculate ultimate bearing capacity foundation (Q_{ult})

Q_{ult} = Q_p + Q_s - W_p (7)
= 12.560,00 + 85,91 – 1.119,787
= 11.522,54 kN

6) Calculate allowable bearing capacity foundation (Q_{all})

Q_{all} = Q_{ult} / FS (8)
= 11.526,12 / 2,5
= 4.610,44 kN

b) Bridge foundation at point 2

The foundation data at point 1 was obtained from Figure 3 cross-sectional of the Aifa bridge foundation with the following data:

- Foundation diameter = 400 cm = 4,0 m
- Foundation depth = 400 cm = 4,0 m
- Foundation material = reinforced concrete

Calculation of the bearing capacity of the caison foundation using field test data in Cone Penetration Test results is carried out with the following stages:

1) Calculate N_{SPT} value = q_c / 4 of conversions for each soil layer. For details on determining value N_{SPT} can be seen Table 6.

Tabel 6. Relationship Between the Value of q_c and N_{SPT} Correction Value

Depth (m) (1)	Cone Resistance (q_c) (kg/cm^2) (2)	N_{SPT} Correction Value (3)	Type of Soil (4)
0.0	0	0,00	Silt Sand
0.2	5	1,25	Silt Sand
0.4	10	2,50	Silt Sand
0.6	10	2,50	Silt Sand
0.8	15	3,75	Silt Sand
1.0	20	5,00	Silt Sand
1.2	28	7,00	Silt Sand
1.4	25	6,25	Silt Sand
1.6	50	12,50	Silt Sand
1.8	70	17,50	Silt Sand
2.0	100	25,00	Silt Sand
2.2	120	30,00	Silt Sand
2.4	150	37,50	Silt Sand
2.6	90	22,50	Sand
2.8	40	10,00	Sand
3.0	48	12,00	Sand
3.2	48	12,00	Sand
3.4	50	12,50	Sand
3.6	57	14,25	Sand
3.8	65	16,25	Sand
4.0	80	20,00	Sand
		∑ = 270,25	

2) Calculate end bearing capacity foundation (Q_p)

A_p = ¼ x π x (D^2) (1)
= 0,25 x 3,14 x (4^2)
= 0,25 x 3,14 x (4^2)
= 12,56 m^2

Q_p = 40 x N_p x A_p (2)
= 40 x 20,00 x 12,56
= 10.048,00 kN

3) Calculate friction skin foundation (Q_s)

A_s = π x D x t (3)
= 3,14 x 4,0 x 4,0
= 50,24 m^2

$N_{average}$ = $\sum N_{SPT} / n$ (4)
= 270,25 / 20
= 13,51

Q_s = 0,1 x N x A_s (5)
= 0,1 x 13,51 x 50,24
= 67,87 kN

4) Calculate self weight of foundation (W_p)

W_p = [(¼.π.($D_{outside}^2$-D_{inside}^2) x D_f x bj. concrete] + [(1/4.π.D_{inside}^2) x Df x bj. cyclop] (6)
= [(¼ x 3,14 x (4^2-$3{,}70^2$) x 4,00 x 24,00] + [¼ x 3,14 x ($3{,}70^2$) x 4 x 22,00]
= (174,082) + (945,705)
= 1.119,787 kN

5) Calculate ultimate bearing capacity foundation (Q_{ult})

Q_{ult} = Q_p + Q_s - W_p (7)
= 10.048,00 + 67,87 – 1.119,787
= 8.996,10 kN

6) Calculate allowable bearing capacity foundation (Q_{all})

Q_{all} = Q_{ult} / FS (8)
= 8.996,10 / 2,5
= 3.598,43 kN

3.4 Bearing Capacity of Foundation Using Soil Parameter Data

a) Bridge foundation at point 1

The foundation data at point 1 was obtained from Figure 3 cross-sectional of the Aifa bridge foundation with the following data:

- Foundation diameter (B) = 400 cm = 4,0 m
- Foundation depth (D_f) = 400 cm = 4,0 m
- Volume of weight (γ) = 1,096 gr/cm^3 x 9,81 = 10,75 kN/m^3
- Cohesion (*c*) = 7,133 kPa = 7,133 kN/m^2
- Internal friction angle (ϕ) = $19{,}60^0$

Calculation of the bearing capacity of the caison foundation using soil parameter data results is carried out with the following stages:

1) Determine the bearing capacity factor of the foundation, (N_c, N_q, N_γ)
From the table of Terzaghi's bearing capacity factor values:
N_c = 17,316 ; N_q = 7,160 dan N_γ = 4,696

2) Calculate end bearing capacity foundation (Q_p)

A_p = ¼ x π x (D^2) (1)
= 0,25 x 3,14 x ($4{,}0^2$)
= 12,56 m^2

q_u = 1,3.c.N_c + D_f.γ.N_q + 0,3.ɤ.B.N_γ (9)
= (1,3 x 7,133 x17,316) + (4 x 10,75 x 7,160) + (0,3 x 10,75 x 4,0 x 4,696)
= (160,57) + (307,88) + (60,58)
= 529,03 kN

Q_p = q_u x A_p (10)
= 529,03 x 12,56
= 6.644,62 kN

3) Calculate self weight of foundation (W_p)

W_p = [(¼.π.($D_{outside}^2$-D_{inside}^2) x D_f x bj. concrete] + [(1/4.π.D_{inside}^2) x Df x bj. cyclop] (6)
= [(¼ x 3,14 x (4^2-$3{,}70^2$) x 4,00 x 24,00] + [¼ x 3,14 x ($3{,}70^2$) x 4 x 22,00]
= (174,082) + (945,705)
= 1.119,787 kN

4) Calculate ultimate bearing capacity foundation (Q_{ult})

Q_{ult} = Q_p + Q_s - W_p (7)

$= 6.644,62 + 0 - 1.119,787$
$= 5.524,83$ kN

5) Calculate allowable bearing capacity foundation (Q_{all})

$Q_{all} = Q_{ult} / FS$ (8)
$= 5.524,83 / 2,5$
$= 2.209,93$ kN

b) Bridge foundation at point 2

The foundation data at point 2 was obtained from Figure 3 cross-sectional of the Aifa bridge foundation with the following data:

- Foundation diameter (B) = 400 cm = 4,0 m
- Foundation depth (D_f) = 400 cm = 4,0 m
- Volume of weight (γ) = 1,096 gr/cm^3 x 9,81 = 10,65 kN/m^3
- Cohesion (c) = 16,030 kPa = 16,030 kN/m^2
- Internal friction angle (ϕ) = 4,46%

Calculation of the bearing capacity of the caison foundation using soil parameter data results is carried out with the following stages:

1) Determine the bearing capacity factor of the foundation, (N_c, N_q, N_γ)
From the table of Terzaghi's bearing capacity factor values:
$N_c = 7,127$; $N_q = 1,535$ dan $N_\gamma = 0,446$

2) Calculate end bearing capacity foundation (Q_p)

$A_p = \frac{1}{4} \times \pi \times (D^2)$ (1)
$= 0,25 \times 3,14 \times (4,0^2)$
$= 12,56$ m^2

$q_u = 1,3.c.N_c + D_f.\gamma.N_q + 0,3.\gamma.B.N_\gamma$ (9)
$= (1,3 \times 16,030 \times 7,127) + (4 \times 10,65 \times 1,535) + (0,3 \times 10,65 \times 4,0 \times 0,446)$
$= (148,52) + (65,39) + (5,70)$
$= 219,61$ kN

$Q_p = q_u \times A_p$ (10)
$= 219,61 \times 12,56$
$= 2.758,31$ kN

3) Calculate self weight of foundation (W_p)

$W_p = [(\frac{1}{4}.\pi.(D_{outside}^2 - D_{inside}^2) \times D_f \times \text{bj. concrete}] + [(1/4.\pi.D_{inside}^2) \times Df \times \text{bj. cyclop}]$ (6)
$= [(\frac{1}{4} \times 3,14 \times (4^2 - 3,70^2) \times 4,00 \times 24,00] + [\frac{1}{4} \times 3,14 \times (3,70^2) \times 4 \times 22,00]$
$= (174,082) + (945,705)$
$= 1.119,787$ kN

4) Calculate ultimate bearing capacity foundation (Q_{ult})

$Q_{ult} = Q_p + Q_s - W_p$ (7)
$= 2.758,31 + 0 - 1.119,787$
$= 1638,52$ kN

5) Calculate allowable bearing capacity foundation (Q_{all})

$Q_{all} = Q_{ult} / FS$ (8)
$= 1638,52 / 2,5$
$= 655,41$ kN

4. CONCLUSION

Based on the results of research and data analysis that has been carried out, the following conclusions can be drawn:

1. From the results of testing the soil characteristics in the laboratory, the type of soil at point 1 is the type of good to bad graded sand soil (SW-SP) with a water content of 17.72%, specific gravity 2.98, liquid limit (LL) = 16,746% included in the non-plastic category. While the location of point 2 is obtained from good to bad graded sand soil type (SW-SP) with a water content of 28.52%, specific gravity 2.73, liquid limit (LL) = 16.746% including the non-plastic category.
2. From the analysis of the calculation of the bearing capacity of the foundation Aifa bridge using data from the sondir test results for point 1 was obtained allowable bearing capacity (Q_{all}) is 4.610,44 kN and for point 2 was obtained allowable bearing capacity (Q_{all}) is 3.598,43 kN. For calculating bearing capacity of the foundation using soil parameter data for point 1 was obtained bearing capacity allowable (Q_{all}) is 2.209,93 kN and for point 2 was obtained allowable bearing capacity (Q_{all}) is 655,41 kN.

5. ACKNOWLEDGEMENT

The authors wish to acknowledge the Ministry of Research, Technology and Higher Education Republic of Indonesia (RISTEKDIKTI-RI) for providing the funds for this research with scheme Beginner Lecturer Research (PDP) year 2019. The author also thanks Ministry of Public Works of the Directorate General of Highways (BPJN XVII Manokwari) for technical data and detail engineering design Aifa bridge.

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