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Design of Stack Foundation in Berau Coal Steam Fire Power Plant on Soft Silty Clay Embankment

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Abstract-Berau CSFPP 2x7 MW is under construction now in Berau river estuary in North Kalimantan province. This power plant has steel structure stack of 40 m height with 3028 mm diameter. Stack foundation is standing on soil embankment of 3,30 m height above original soil to anticipate tidal river water level and to have plain level in power plant areas. Below the embankment, original soil are consist of very soft-soft silty clay in 1-14 m depth with N-SPT = 1-2, qc = 1-21 kg/cm2; soft-medium stiff clayey silt in 14-23 m depth with N-SPT = 3-15, qc = 22-38 kg/cm2 and very stiff-hard silty clay in 24-30 m depth with N-SPT = 16-23, qc = 39-47 kg/cm2. Based on this condition, stack foundation has been designed with 25 points concrete pile K.600, Ø = 400 mm and 30 m length. Design loads are consist of deadly weight stack, pile cap, concrete pile; wind load at top of stack in 120 km/hours velocity; earthquake; impact load and uplift force due electromechanical vibration; extended moment due eccentricity and negative skin friction. Pile stabilization calculation are satisfied enough i.e. bearing capacity ratio 1,63; safety factor for block failure 1,03 and uplift 8,47; settlement 3,25 cm.

Keywords : stack, driven pile, soft clay

1. Introduction

Berau Coal Fire Steam Power Plant (CFSPP) 2x7 MW is located in TanjungRedeb district, Berau region, North Kalimantan province near Berau river estuary. This power plant is under construction now as electricity project sustainable development in Berau industrial zone by National Electricity Company (PT PLN) Main Plant Project Unit IX Kalimantan. Berau CFSPP is the second power plant in Berau area after Lati CFSPP 2x7 MW which has operated in 2005. Electrical energy from Berau CFSPP will be supplied to coal mining industry, crude palm oil factories and social users around industrial area.

Project location is nearby Berau river estuary so that top soil type is soft soil like silty clay which is until 20 m depth with N-SPT value < 10 and conus resistance qc< 25 kg/cm2 (Soenoe, 2011). Based on this condition, the project management has decided to make reclamation until 3,30 m height above original soft soil to anticipate tidal river water level and to obtainthe flat surface in whole power plant areas (PT PLN UIP IX, 2014). The foundation type that should be used is the deep foundation like driven or bored pile. This solution is in accordance with technical requirement or specification contract document part 4 section 4.5.1.7., 4.5.2.5. and4.5.2.8.

Upper structure stack or flue liner is circular type made from welded steel plate ASTM A36/SS400 with 40 m height. Outer diameter at top is 2250 mm with 10 mm thick and at bottom is 3028 mm with 14 mm thick. For maintenance, there are 2 section steel ladder, section 1 is 15 m height and section 2 is 25 m height. Upper steel structure should be tied with 30 pieces anchor bolts @ diameter 42 mm to concrete pile cap which supported 25 points concrete spun piles.

2. Theoretical Background

Upper structure stack loading consist of dead load, live load, steel pipe expansions and shrinkage load, dynamic/impact load due gas released, construction loads during steel erection, wind load, seismic load and other loads as given by electromechanical equipment manufactures. Dead loadsare all steel structures includes miscellaneous requirement such platform, handrailing, grating, checkered plate, ladder, lightning, fire fighting, grounding, lighting and emergency lamp steel support and its appurtenances. Live load used Indonesian Building Loading Code (1987) and PT PLN's Loading Code is 500 kg/m2. Steel pipe expansions and shrinkage loads are designed for 0-455^{o} C temperature and 20 years life time period corrosion protection. Dynamic or impact load is 20% times electromechanical equipment weight. Construction load is 500 kg/m2 as PT PLN's Loading Code. Wind load shall be designed based on wind velocity 120 km/hour. Seismic load shall be calculated in zone 2 accordance with Indonesian Earthquake Building Design Standard (2002) with peak ground acceleration minimum 0,03 g. There are six load combination based on SNI 03-2847-2002 :

- Comb.1 = 1,40.DL
- Comb.2 = 1,20.DL + 1,60.LL
- Comb.3 = 1,20.DL + 1,00.LL + 1,00.E(x) + 1,30.W(x)
- Comb.4 = 1,20.DL + 1,00.LL + 1,30.E(x) + 1,00.W(x)
- Comb.5 = 1,20.DL + 1,00.LL + 1,30.E(y) + 1,00.W(y)
- Comb.6 = 1,20.DL + 1,00.LL + 1,00.E(y) + 1,30.W(y)

All these upper structure calculations has been designed by electromechanical team works, and civil team work received the result of joint/support reaction at pile cap as compression, uplift and lateral forces also moment in x and y direction. These reactions will be used to design pile cap and concrete pile stability.

Substructure shall be designed as driven pile group which considered efficiency by Converse-Labarre formula. Distance between each pile is (1,50-3,00) x pile diameter and distance from outer pile to the edge ofpile is (1,00-1,50) x pile diameter. Allowable pile bearing capacityis calculated by using N-SPT and DCPT data. Suyono and Nakazawa (1984) said that Qall is the amount of base resistance Qd and shear resistance Qf then divides with safety factor 2-3. Qd depends on N-SPT value's average and pile's cross sectional, Qf depend on pile's diameter and shear resistance along pile's perimeter. If use DCPT data, Meyerhoff (1976) stated that Qall is amount of base resistance Qd divides safety factor 3 and shear resistance Qf divides safety factor 5. Qd depend on pile's cross sectional and qonus resistance, Qf depend on pile's perimeter and total friction. For safety, engineer usually will choose the smallest allowable bearing capacity between two formulas above (N-SPT or DCPT data). In the site, this bearing capacity must be smaller than allowable axial load and crack bending moment as given by pile's manufacturer and also smaller than the result of loading test. Stability of pile's should be considering negative's skin friction due soil embankment, lateral displacement, deflection, settlement, uplift stability and block failure.

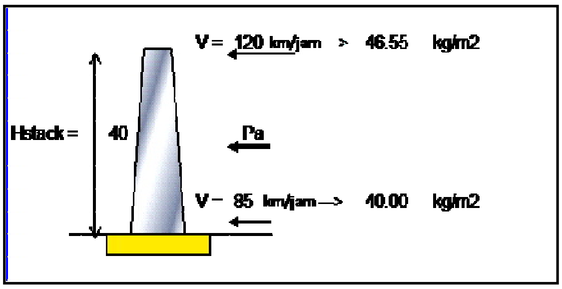

Fig. 1. Wind load at stack

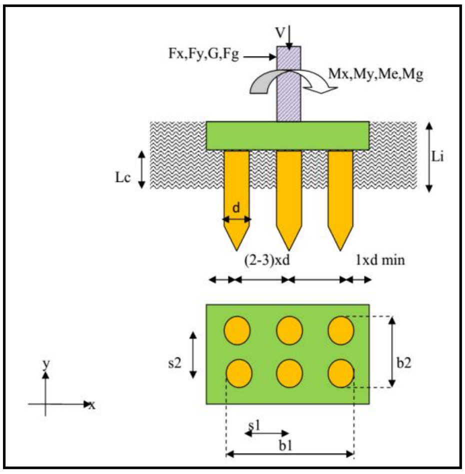

Fig. 2.Forces and moment in pile cap and pile group

$$Px = \frac{\sum V}{m.n} + \frac{Mx.x_i}{\sum x_i^2} + \frac{(M_y+M_e+M_g+M_a).y_i}{\sum y_i^2} \qquad (1)$$

3. Result and Discussion

Soil's layer as described in log borand DCPT data are explained in table 1 below. Based on this condition, foundation will be designed as pile group 5x5 points along 30 m using concrete spun pile diameter 400 mm. Support or joint reaction from upper structure to pile group are Fz(+) = 80 ton, Fz(-) = 0 ton, Fx = 6,69 ton and Fy = 6,60 ton. Then impact load Fg is equal 20% times stack dead load = 6,60 ton and seismic load G in ground surface is 6,06 ton. Wind velocity in top of stack is 120 km/hour and in the bottom is 85 km/jam so the average wind pressure Pa at stack is λ . (42,50+0,60.H_{stack}) = 43,28 kg/cm2, wind load Ha = Pa . (cross sectional of stack) = 5,87 ton. Assumption negative skin friction Pnf is worked at soil embankment 3,30 m thick plus very soft silty clay and loose silty sand 14 m thick.

Table 1. Soil and engineering properties in S-5 and BH-05

No	Depth (m)	Description	N-SPT	qc (kg/cm2)	tf (kg/cm)	c (kg/cm2)	Ø (°)	ɣ (t/m3)
1	0-5	Silty clay, very soft	1	1-3	2-64	0,25	2,69	1,74
2	5-14	Silty sand, very loose	1-2	3-21	64-404	-	-	-
3	14-28	Silty clay, soft- very stiff	2-23	21-47	404-1456	0,57	4,50	1,62
4	28-45	Silty clay, very stiff and hard	23-48	-	-	-	-	-

For safety reason, pile bearing capacity was calculated based on N-SPT value by using Meyerhof's formula which enhanced by Suyono and Nakazawa (1984) into equation below :

$$\text{Qult} = \{(\text{qd} \cdot A_{\text{pile}}) + \pi \cdot D_{\text{pile}} \cdot (\sum l_i \cdot f_i)\} \quad (2)$$

$$\text{Qall} = \text{Qult} / \text{FS} \rightarrow \text{FS} = 2 - 3 \quad (3)$$

So we have Qall = 34,67 ton with FS = 3 for pile Ø 400 mm in 30 m depth. There are 5 rows pile in x direction and 5 lines pile in y direction with piles distances are 1,20 m both side. Pile efficiency is 0,67 so P_{all} = 23,31 ton is smaller than allowable axial load as given by pile's manufacturer = 121,10 ton and the result of nearest loading test = 48 ton in the same depth and pile's diameter. Meanwhile, actually load Pact at pile consist of compression Fz(+), pile cap and piles dead load W_{cap}+ W_{pile} , negative skin frictionPnf = 357,17 ton/25 piles = 14,29 ton/piles is smaller than P_{all} = 23,31 ton, so it is ok. For uplift st ability, the ratio between $W_{cap}$and shear resistance along pile's group perimeter with uplift forces due impact load, wind load and seismic load mu st be greater or equal 2,00 (Hardiyatmo, 2006). From calculation was obtained safety factor 8,74> 2,00 and it is safe.

$$\text{FS}_{\text{uplift}} = \frac{W_{\text{cap}} + \pi \cdot D_{\text{pile}} \cdot (\sum l_i \cdot f_i) \cdot n_{\text{pile}} \cdot \tan\delta}{F_g + H_a + G} > 2{,}00 \quad (4)$$

Block failure stability should be designed as shown in equation below (Hardiyatmo, 2006, p.141) :

$$\text{FS}_{\text{block}} = \frac{2 \cdot L_{\text{pile}} \cdot (B+L) \cdot (\sum l_i \cdot f_i)}{P_{\text{actual}}} > 2{,}00 \quad (5)$$

The result is FS_{block}= 1,03> 1,00 with total friction along pile group perimeter only 10% supported.

Design of allowable piles bearing capacity must be checked in site with loading test and PDA test. The result of loading test showed that pile bearing capacity was 48 ton in 30 m depth with settlement 3.08 cm. PDA test was generate pile bearing capacity 71 ton (with FS = 3,00) in 27,50 m depth with settlement 2,55 cm, lateral displacement Dy = 2,15 cm and Dx =

2,25 cm, compressive strength of concrete was occurred 29,3 MPa (Agustina, 2013). Meanwhile, the design load is 23,31 ton so it is safe.

Table 2. PDA test result

No. Tiang	Penampang (cm)	Panjang Tiang Terbenam(m)	Blows Number	Kapasitas Dukung CAPWAP Termobilisir (ton)		
				Selimut	Ujung	Ultimate
1	∅ 40	27.5	30	161	54.4	215.4
16	∅ 45	24	3	166.1	49.1	215.2
Unused	∅ 40	54.05	8	105	20.3	125.3

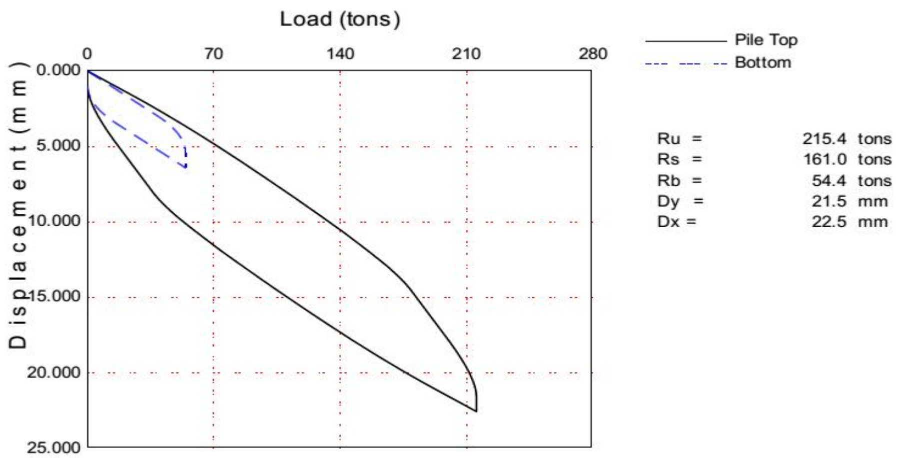

Fig. 3. Ultimate pile bearing capacity and displacement by PDA test

Pile cap dimension is 6,00x6,00x1,20 m so the upper pile should be entered 60 cm minimum into pile cap so the pile can be classified as fixed end pile (Hardiyatmo, 2006, p.205). Fixed point of pile $z_f$was assumed in 1/3 of pile length than the deflection and moment capacity in pile tip can be calculated by graphics correlation total lateral force V and characteristic shear strength Vc, by Evans and Duncan (1982).

$$\mathbf{V} = \sqrt{(\mathbf{F_x^2} + \mathbf{F_y^2} + \mathbf{F_g} + \mathbf{H_a} + \mathbf{G})}(6)$$

$$\mathbf{V_c} = \boldsymbol{\lambda} \, . \, \mathbf{d^2} . \, \boldsymbol{E} \, . \, \boldsymbol{R_1} \, . \left(\frac{\sigma_p}{E.R_1}\right)^{\mathbf{m}} . \, (\boldsymbol{\varepsilon_{50}})^{\mathbf{n}}(7)$$

So from graphics 2.86 and 2.89 (Hardiyatmo, 2006, p. 240-242) itcan be computed the total deflection at pile tip is 0,32 cm < allowable deflection = 0,78 cm and maximum moment at pile tip is 0,57 tm < capacity moment = 1,05 tm < crack moment = 5,50 tm, therefore pile group is safe.

Settlement of pile can be affected by immediate settlement of sand and soft soil in depth 0-14 m, also consolidation settlement of silty clay in depth 14-30 m. Tomlinson (1963) said to predict settlement in soft clay which is positioned between embankment soil above and stiff-hard clay below , based on Terzaghi and Peck's research in 1948, we can assumed that in depth 2/3 pile length fromground level is floating foundation with bearing area is width times length of pile group. Settlement equation as shown below by Janbu method (Hardiyatmo, 2006, p.233, 254) :

$$\mathbf{S_i = \mu_1 \cdot \mu_o \cdot \frac{q \cdot B}{E}} \quad (8)$$

$$\mathbf{S_c = \sum_{i=1}^{i=n} m_{vi} \cdot \Delta p \cdot \Delta H} \quad (9)$$

S_i is immediate settlement depending on correction factor of soil thick μ_1 and foundation depth μ_2, Pact, B and L pile's group, soil's elasticity modulus E. S_c is consolidation settlement depending on volume coefficient m_v, Pact, width B and length L of pile's group, extension pressured, depth of each soil's type. Settlement calculation used Steinbrenner and Janbuet.al'sgraphics so that the results of $S_i$is 0,85 cm and S_c is 2,40 cm so total S = 3,25 cm. Settlement time was predicted to occur after 50 years.

Pile cap reinforcement has been calculated as a beam with fixed joint in one side and unmoving joint in another side. Moment resulting from P_{act} times a half of pile cap's width thus obtainedrebar D16-200 in upper and bottom pad. Pile cap dimensions should be checked due shear strength, friction and punching from P_{act} effect.

Anchor bolt must be designed to hold compressive, lateral and uplift force without causing concrete's crack as equation below.

$$\mathbf{S_1 = \frac{1{,}25.N}{A_r} \leq \overline{\sigma}} \text{ and } \boldsymbol{S_2 = \frac{\sqrt{(N^2 + 2{,}36.T^2}}{A_r} \leq \overline{\sigma}} \quad (10)$$

$$\mathbf{T = \frac{1}{4} \cdot \sqrt{F_x^2 + F_y^2} \leq \overline{\sigma}} \quad (11)$$

$$\mathbf{P_{act} = N_{max} = 0{,}10 \cdot \left(1 + \frac{7.\ \gamma_c}{1000}\right) \cdot \left\{\frac{\theta}{\left(1 + \frac{\theta}{d_t}\right)^2}\right\} \cdot (L_a + 6{,}40.R + 3{,}50.L_1)} \quad (12)$$

S_1 is compressive strength, S_2 is total compressive strength due resultant compressive force with shearing force. θ is bolt diameter, $d_t$is distance from bolt axis to outer side of pile cap, L_a is bolt length, R is bending radius of end bolt, L_1 is length of hook bolt. The computation's result is shown that stack must be tied with 30 pieces anchor bolts SS 400 @ diameter 42 mm with length 1000 mm around pile cap's surface.

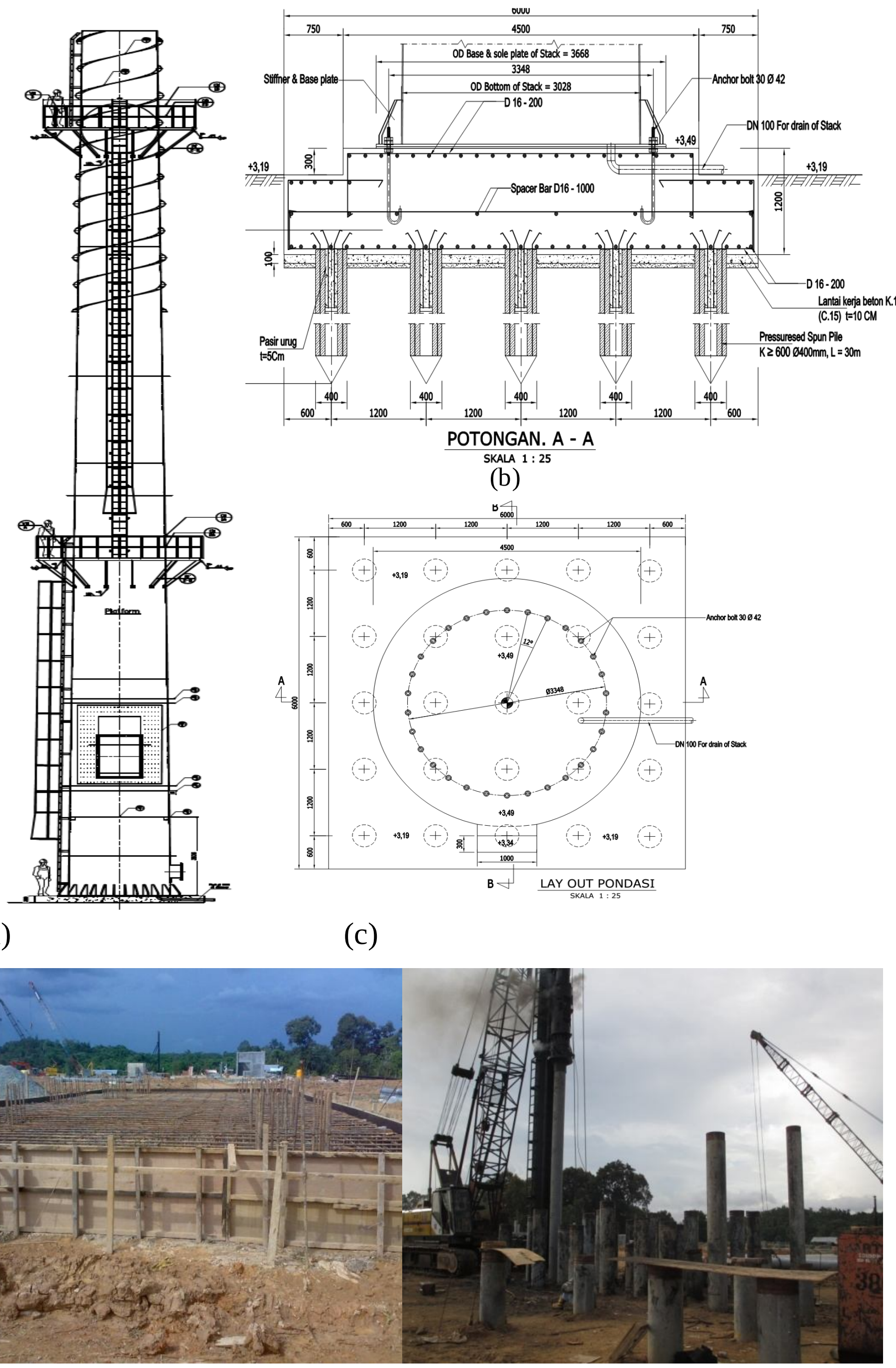

Fig. 4. (a) Side view of stack, (b) pile cap reinforcement, (c) pile layout, (d) piling in site, (e) pile cap was ready to concreting

4. Conclusion

Stack's construction is circular type made from welded steel plate ASTM A36/SS400 with 40 m height. Outer diameter at top is 2250 mm with 10 mm thick and at bottom is 3028 mm with 14 mm thick. Stack's foundation is concrete spun pile 25 points @ diameter 400 mm with 30 m length above selected soil embankment 3,30 m thick and soft silty clay 18 m thick. All piles was tied with pile cap 6,00x6,00x1,20 m to withstand compression force, lateral pressure, uplift and moment. These forces come from dead load, live load, steel pipe expansions and shrinkage load, dynamic/impact load due gas released, construction loads during steel erection, wind load, seismic load, impact load, negative skin friction and other loads as given by electromechanical equipment manufactures.

Calculation result indicatesthat actuallymaximum compression load is 14,29 ton/piles is smaller than allowable pile group bearing capacity 23,31 ton/piles, allowable axial load as given by pile's manufacturer = 121,10 ton, the result of nearest loading test = 48 ton and PDA test = 71 ton. Uplift stability safety factor is 8,74> 2,00 and block's failure safety factor = 1,03 > 1,00. Deflection at pile tip is 0,32 cm < allowable deflection = 0,78 cm and maximum moment at pile tip is 0,57 tm < capacity moment = 1,05 tm < crack moment = 5,50 tm. Total immediate and consolidation settlement is 3,25 cm and predicted to occur after 50 years.

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