Foundation options of a stacker reclaimer

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ABSTRACT

With the rapid development and expansion of port in the South-East Asia region, many infrastructure projects have been constructed at the coastal areas. Recently, as part of development of Eastern Industrial Corridor project, ports at east coast of Malaysia have been undergoing expansion to increase their capacity. Minerals such as iron and coal distribution centres are being set up at the east Coast of Malaysia. The port generally serves as a gateway connecting the mine products from South America to the consumer markets in Asia. The facilities are expected to comprise of a stockyard equipped with stacker reclaimer when in operation. It is well known that ground conditions at the coastal area pose significant challenges to the geotechnical engineers. The stockpile of iron and coal ores is envisaged to exert a significant pressure to the existing ground condition which consists of reclaimed sand overlying thick alluvial clays. Due to close proximity of the stockpile of iron and coal ores to the operating stacker reclaimer, selection of foundation of stacker reclaimer becomes difficult and thus a challenging task. This paper aims to discuss the foundation options of a stacker reclaimer under coastal ground conditions. Analyses with the aid of finite element methods using commercial software, known as Plaxis 3D, are discussed in details.

Keywords: Pile Group, Stacker Reclaimer, Unbalanced Loading, Settlement, Iron and Coal Ores, Lateral Pressure

1 INTRODUCTION

With the rapid development and expansion of port in the South-East Asia region, many infrastructure projects have been constructed at the coastal areas. Recently, as part of development of Eastern Industrial Corridor project, ports at east coast of Malaysia have been undergoing expansion to increase their capacity. Minerals such as iron and coal distribution centres are being set up at the east Coast of Malaysia. The facilities are expected to comprise of a stockyard equipped with stacker reclaimer when in operation. The stockpile of iron and coal ores is envisaged to exert a significant pressure to the existing ground condition which consists of reclaimed sand overlying thick alluvial clays. Literature showed that deep and shallow foundation systems (Peck and Raamot, 1964; Powell and Harris 1977) have been used successfully at stockyard areas. This paper attempts to explore the feasibility of pile and shallow foundation options for stacker reclaimer with emphasis on the use of three-dimensional finite element method.

2 GROUND CONDITION

In our site investigation campaign, a total of eleven exploratory boreholes have been drilled to a depth of approximately 55m into competent residual soil. Our site investigation revealed that the ground condition of the site generally consists of thick reclaimed sand fill overlying the alluvial deposits (sandy silt and sandy clays), dense to very dense sands. The underlying base formation materials are of residual soils. The groundwater is about 4.5 meters below the ground surface.

The sand fill has an average thickness of about 12.5m, with the standard penetration test (SPT) blow counts ranging from 9 to 94. It appears that the sand layer has been compacted to some extent. Based upon the site history, it also seems that the underlying clayey materials has been ground improved with an average over-consolidation ratio (OCR) of about 1.7 and undrained shear strength, c_u ranging from 70 kPa to 220 kPa. The native sandy materials were of medium dense to very dense in term of relative density, and often were sandwiched between clayey materials. Competent residual soils with SPT more than 50 were encountered at a depth of about 50m. A representative generalized soil model of the site is illustrated in Fig. 1.

Fig. 1. Representative soil model.

3 STOCKYARD DETAILS

Two railway tracks, spanning about 450m in length, will run parallel to each other. Two ore types, namely iron and coal will be stacked and reclaimed at the new port. A typical sectional view of the stacked ores is presented in Fig. 2. The operating stacker reclaimer is estimated to be about 6000 kN while the unit weights of the iron and coal ores are estimated to be 24 kN/m^3 and 8 kN/m^3, respectively. The iron ore will be stacked to a maximum height of 5.45m while the coal ore will be stacked to a maximum height of 12.5m. The base width of the stockpiles is 40m.

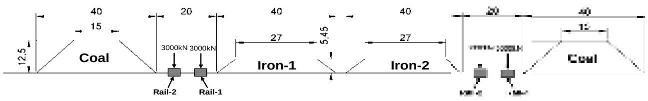


Fig. 2. Typical plan and sectional view of stockpile area.

4 METHODOLOGY

A finite element analysis software, PLAXIS 3D was used in this study. PLAXIS 3D enables three-dimensional analyses to be performed on the soil-structure interactions, thus eliminating the uncertainty in 2D model when three-dimensional effect is inevitably needed in some loading arrangements. In the finite element analysis, all the soil materials were simulated as Mohr-Coulomb (MC) model, except the sandy silt (MSSS material) and medium stiff sandy clay (MSSC material) were simulated as soft soil (SS) model. The soil parameters are summarized in Table 1. Considering long-term effect, the analysis was carried out under steady-state conditions.

Table 1. Summary of soil parameters

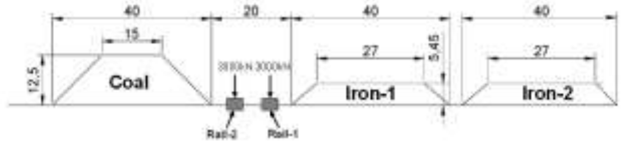
Layer	γ_{sat}	c'	ϕ'	c_u	E'	k	Consolidation Parameter			
	kN/m^3	kPa	°	kPa	MPa	m/s	OCR	e_0	c_r	c_c
Fill	17*/18	0	35	-	2.5N	10^{-5}	-	-	-	-
MSSS	19.0	0	24	-	-	10^{-8}	1.7	0.8	0.04	0.25
MSSC	18.5	0	22	70	11.5	10^{-10}	1.7	0.7	0.09	0.55
VstC	18.0	0	22	150	25.0	10^{-8}	-	-	-	-
DVDS	20.0	0	35	-	2.5N	10^{-6}	-	-	-	-
RS1	20.0	1	30	-	2.5N	10^{-6}	-	-	-	-
RS3	20.0	5	32	-	2.5N	10^{-6}	-	-	-	-

Note: *indicates unit weight above groundwater level.

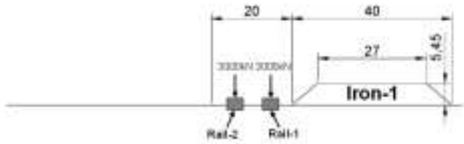
4.1 Loadings and Requirements

The loadings imposed by the ore stockpile, are of critical in the design of foundations for the stacker reclaimer. During operation, it is unclear how the stockpiles will be placed. As such, a series of different critical loading scenarios, as shown in Fig. 3, have been hypothesized in the design of foundations for stacker reclaimer. These include:

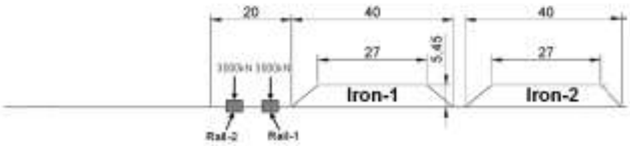
Scenario 1: Applying a maximum height of one stockpile of coal ore and two stockpiles of iron ore.
Scenario 2: Applying a maximum height of one stockpile of iron ore.
Scenario 3: Applying a maximum height of two stockpiles of iron ore.



(a) Scenario 1



(b) Scenario 2



(c) Scenario 3

Fig. 3. Envisaged critical stockpile loading configuration.

It is expected that during operation stage, the following requirements have to be fulfilled:

1. The maximum differential settlement between Rail-1 and Rail-2 should be limited to 1:600.
2. The total maximum differential settlement of rail track in longitudinal direction (i.e., for total length, L=450m) should be limited to 1:1000.
3. The local maximum differential settlement of rail track in longitudinal direction (i.e., for length between two supporting foundations in longitudinal direction) should be limited to 1:300.

4.2 Pile Foundations

For pile foundations, both driven spun piles and bored piles were considered. All the piles have been designed with toe socketed 1m into competent residual soil, where the SPT-N > 50, representing end-bearing piles. To investigate the floating pile behaviour, one option of spun pile group was modelled where the pile toe terminates in clay layer (MSSC) at about CD-16.0m. The following five options, as illustrated selectively in Fig. 4 have been included in this study.

Option 1: Raked spun pile with a diameter of 600 mm

and the rake angle is 1H: 7V. Each pile group consists of four number of piles.
Option 2: Same as above except the piles are vertical.
Option 3: Same as Option 2, except pile toe terminates in clay layer (i.e. floating pile model).
Option 4: Same as Option 2, except jet grouting pile (JGP) with a 2m thick wall is installed between the pile group and the toe of embankment. Based on local practice, the JGP's design undrained shear strength and elastic modulus are 250 kPa and 150 MPa, respectively.
Option 5: Single bored pile with a diameter of 1.0m.

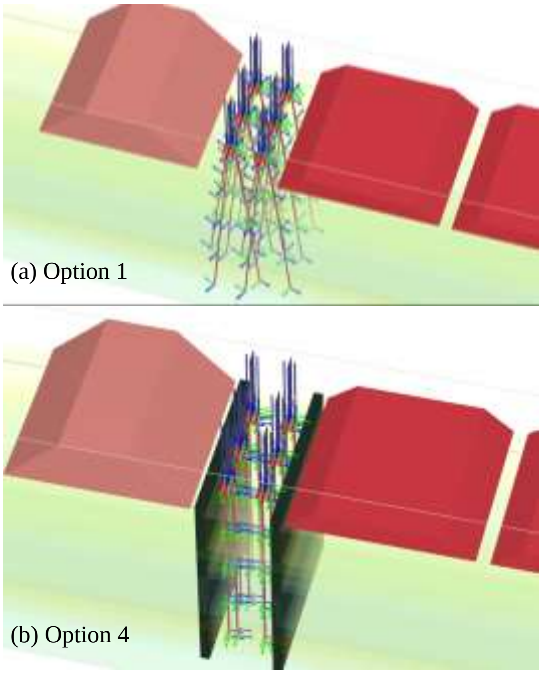
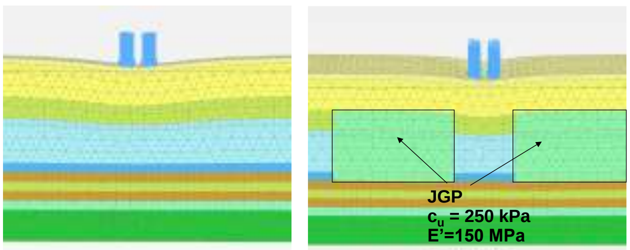

(a) Option 1
(b) Option 4

Fig. 4. Pile foundations options.

4.3 Shallow Foundations

Based on our site investigation, relatively good soil was encountered at shallow depths. This provides an opportunity for the stacker reclaimer to be supported by footing foundation. For preliminary design, all the square footing has been designed with a width of 2.7m. The shallow foundation options are illustrated in Fig. 5. The following two options have been included in this study.

Option 6: No ground improvement (i.e., as is, existing condition).
Option 7: JGP ground improvement below stockpiles of coal and iron ores.



(b) Option 7

(a) Option 6

Fig. 5. Shallow foundations options.

5 RESULTS AND DISCUSSIONS

Table 2 presents the analyses results for all the foundation options. The induced pile's bending moment, vertical and horizontal displacement of pile caps/footing, and rotation between Rail-1 and Rail-2 have been summarized under different operation scenarios.

For Option 1 (Raked spun pile), due the exertion of lateral pressure by stockpile loadings, the maximum bending moments induced were ranging from 364 kNm (i.e., Scenario 1 with three full coal and iron stockpiles) to 377 kNm (i.e., Scenario 2 with one full iron stockpile). The corresponding lateral pile displacements were 31 mm and 39 mm, respectively. A typical lateral displacement and bending moment of pile under Scenario 2 is presented in Fig. 6. It can be seen that the maximum induced bending moment of pile was located between the interface of sand fill and clayey material. It is likely that it is due to the abrupt change of maximum pile curvature at that interface when stockpile loading was applied. It should be noted that under working load due to the self-weight of stacker reclaimer, the axial force of pile is only about 1000 kN. However, when stockpile loading is applied, the maximum axial force increases to about 3500 kN. This suggests that drag force has taken place due to the more relatively settlement adjacent to the pile. The differential settlement between two rail pile caps was ranging from 8 to 23 mm. The corresponding rotation is estimated to be ranging from 1:1000 to 1:347, where the larger rotation is associated with larger unbalanced loading scenario.

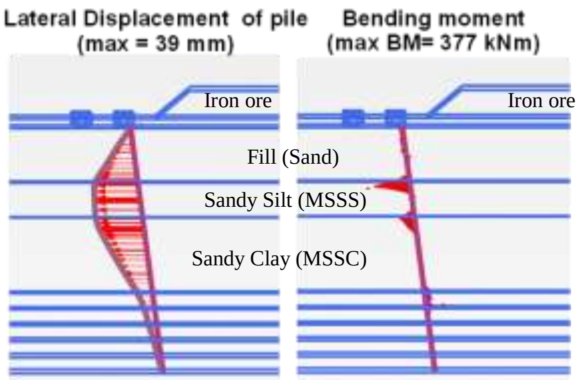


Fig. 6. Lateral displacement and bending moment of raked piles.

For Option 2 (Vertical spun pile), the maximum bending moments induced was about 359 kNm and the maximum axial force was about 3200 kN. The results suggest that there is a reduction in bending moment and axial force for vertical piles as compared to raked piles. This can be expected, as a higher degree of raking angle will result in a higher bending moment and axial force due to the presence of soil weight above the raked piles.

As compared to Option 2, the maximum bending moments induced for friction/floating spun pile group (Option 3) was reduced to about 254 kNm (i.e., about 30% reduction) while the maximum axial force was reduced to about 1150 kN (i.e., about 64% reduction). However, the maximum settlement has increased to 130 mm as compared to 38 mm for end-bearing pile group. The results showed that significant drag force can be expected in end-bearing piles, where movement of pile is restricted, and should not be overlooked.

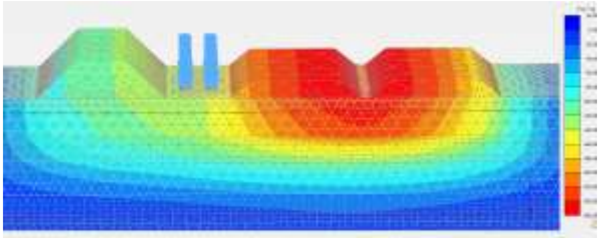


Fig. 7. Settlement profile under Scenario-1 for Option 7.

For Option 7 (Footing with soil improvement below stockpile), the maximum settlement of footing was ranging from 42 to 56 mm when stockpile loading is applied under different scenarios. The corresponding rotation between two rail footings was estimated to be ranging from 1:2000 to 1:727. A typical settlement profile under Scenario 1 for Option 7 is presented in Fig. 7. This option is deemed as idealized condition, as settlements can be kept well within the tolerable limits, however, this may also be a very costly option.

Table 2. Summary of analysis results for all the foundation options

Options	Scenario	Rail-1						Rail-2						Rotation (over a distance of 8m)
		Individual Pile				Pile Cap/Footing		Individual Pile				Pile Cap/Footing		
		Max. Axial Force (kN)	Max. Bending Moment (kNm)	Max. Vertical Disp. (mm)	Max. Lateral Disp. (mm)	Max. Vertical Disp. (mm)	Max. Lateral Disp. (mm)	Max. Axial Force (kN)	Max. Bending Moment (kNm)	Max. Vertical Disp. (mm)	Max. Lateral Disp. (mm)	Max. Vertical Disp. (mm)	Max. Lateral Disp. (mm)	
1. Raked Spun Piles	1	3556	364	41	31	41	6	3277	177	33	6	33	3	1:1000
	2	3220	377	36	39	36	1	1884	82	14	24	14	3	1:363
	3	3364	370	37	44	37	4	1762	87	14	26	14	4	1:347
2. Vertical Spun Piles (end-bearing pile)	1	3183	338	38	26	38	6	3088	134	34	8	34	3	1:2000
	2	3007	359	32	35	32	2	1284	84	16	26	16	3	1:500
	3	3038	348	33	41	33	3	1176	88	15	28	15	4	1:444
3. Vertical Spun Piles (friction/floating pile)	1	1085	157	131	24	131	5	991	65	115	17	115	3	1:500
	2	1141	254	110	36	110	7	662	200	75	33	75	9	1:229
	3	1084	223	107	39	107	10	671	179	71	35	71	10	1:222
4. Vertical Spun Piles with 2m thick JGP wall	1	2743	83	33	24	33	2	1885	32	26	11	26	2	1:1143
	2	2640	102	29	31	29	2	1325	77	16	24	16	3	1:615
	3	2662	102	29	37	29	3	1244	89	16	27	16	4	1:615
5. Single Bored Piles 1m dia.	1	7211	743	69	23	69	6	6870	200	67	12	67	1	1:4000
	2	6812	1220	57	36	57	5	5444	640	38	30	38	4	1:421
	3	6776	1111	57	40	57	9	5234	566	35	31	35	4	1:364
6. Footing: without soil improvement	1	-	-	-	-	172	9	-	-	-	-	154	7	1:444
	2	-	-	-	-	149	18	-	-	-	-	108	22	1:195
	3	-	-	-	-	149	21	-	-	-	-	108	22	1:195
7. Footing: with soil improvement below stockpiles	1	-	-	-	-	56	1	-	-	-	-	52	0	1:2000
	2	-	-	-	-	53	2	-	-	-	-	42	1	1:727
	3	-	-		-	53	2	-	-	-	-	42	1	1:727

For Option 4 (Vertical spun pile with JGP wall), the maximum bending moments induced has significantly been reduced to approximately 100 kNm. This is likely that the JGP wall provides a barrier protection zone for the pile from being exposed to the direct lateral pressure induced by stockpile loading. However, this should be verified at site with caution. For Option 5 (Single bored pile with 1m dia.), the maximum bending moments induced was about 1220 kNm, which is approximately 3.4 times higher than that of a 600 mm dia. spun piles. This can be expected as pile with higher flexural rigidity tends to draw more bending moments.

For shallow foundation, the finite element study showed that under existing soil condition (i.e. Option 6), the footing may subject to a maximum total settlement ranging from 108 to 172 mm for different critical stockpile loading. This results in a rotation ranging from 1:444 to 1:195. However, with the aid of instrumentation monitoring programme, occasional "re-ballast" of rail alignment may provide an economical option when total or differential settlement/rotation limit (i.e., work suspension level) has been breached. It should be noted that this will only be viable, if disruption of operation can be tolerated.

6 CONCLUDING REMARKS AND SPECIAL CONSIDERATION

Operating structures founded on coastal area are often susceptible to serviceability problem, due to the presence of unfavourable clayey deposits. In this paper, the foundation systems of a stacker reclaimer have been explored in details. These include pile and shallow foundations, with/without ground improvement. For pile foundations (i.e. end-bearing type), additional drag force induced by settlement underneath the stockpile (i.e. adjacent to the piles) should not be overlooked when designing pile capacity. The finite element analyses also showed that unbalanced loadings due to the stockpile, are of a major concern. If differential settlement can be controlled by having a clear and stringent standard operating protocol on stockpile (e.g. avoid extreme unbalanced stockpile), footing without soil improvement (i.e., Option 6) may appear to be the most cost-saving option. Further analyses are required to establish the guidance on stockpile loading.

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